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Evaluation of Full-Scale Sugar Beet Transport Water Solids Dewatering System

Sverdrup and Parcel and Associates, Inc.
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16. ABSTRACT

The objectives of this study were to evaluate a full-scale vacuum filtration system for dewatering solids removed from the transport water in an operating beet sugar plant in terms of operational reliability and efficiency, economics, and ultimate disposal of the dewatered solids.

At the plant study site (MINN-DAK Farmers Cooperative, Wahpeton, North Dakota), the solids in the beet transport water are removed in a clarifier and piped to the Mud House. Waste lime mud from the sugar processing is added to the clarifier underflow to serve as a filter aid. The combined sludge is dewatered on two vacuum filters. The filter cake is pumped to a storage lagoon adjacent to the Mud House.

Study findings indicate that the solids handling system was not functioning as intended, largely because the clarifier did not provide sufficient thickening. The vacuum filters received primarily waste lime mud; the clarifier underflow largely bypassed the Mud House and went directly to a storage lagoon. Mud House operations were adjusted to compensate for the various difficulties, resulting in bypass of most of the clarifier underflow.

Because the solids handling system was not functioning as intended, the economic evaluation was not carried out. Instead, the various components of the total system were evaluated and modifications are presented that can be implemented to improve the system so that the original goals for the system can be achieved.

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May 1980

EVALUATION OF FULL-SCALE SUGAR BEET TRANSPORT WATER SOLIDS DEWATERING SYSTEM

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The report evaluates a full-scale sludge dewatering system at an operating beet sugar plant. The system was intended to enhance disposal options and decrease odor potential by reducing the water content of waste solids.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The objectives of this study were to evaluate a full-scale vacuum filtration system for dewatering solids removed from the transport water in an operating beet sugar plant in terms of operational reliability and efficiency, economics, and ultimate disposal of the dewatered solids. A post-campaign study was also carried out to measure and characterize the odors associated with beet sugar waste storage lagoons. The study provided an opportunity to verify the findings of a 1972 study carried out under EPA sponsorship (Grant 12060 ESC).

The site of this study was the MINN-DAK Farmers Cooperative in Wahpeton, North Dakota. At this plant, the solids in the beet transport water are removed in a clarifier and piped to the Mud House. Waste lime mud from the sugar processing is added to the clarifier underflow to serve as a filter aid. The combined sludge is dewatered on two vacuum filters. The filter cake is pumped to a storage lagoon adjacent to the Mud House. The solids handling system is operated 24 hours per day, seven days a week during the campaign.

The findings of the study indicate that the solids handling system was not functioning as intended. The vacuum filters received primarily waste lime mud; the clarifier underflow largely bypassed the Mud House and went directly to a storage lagoon. The major cause of this malfunction was that the clarifier did not provide sufficient thickening. Other causes include several minor design deficiencies and deviations from the criteria developed in the earlier study. Operations in the Mud House were adjusted to compensate for the various difficulties, resulting in bypass of most of the clarifier underflow.

Because the solids handling system was not functioning as intended, the economic evaluation was not carried out. Instead, the various components of the total system were evaluated and modifications are presented that can be implemented to improve the system so that the original goals for the system can be achieved.

This report was submitted in fulfillment of Task Order 10 of Contract No. 68-01-3289 by Sverdrup & Parcel and Associates, Inc., St. Louis, Missouri under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September, 1976 to July, 1977, and work was completed as of December, 1978.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD -- biochemical oxygen demand

COD -- chemical oxygen demand

cu m/day -- cubic meters per day

GC -- gas chromatography

gpd/sq ft -- gallons per day per square foot

kg/sq m/day -- kilograms per square meter per day

mg/l -- milligrams per liter

ou/cf -- odor units per standard cubic foot

TDS -- total dissolved solids

SYMBOLS

Ca -- calcium

CaO -- calcium oxide

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Mr. Donald L. Stewart, of Stewart C&R, Inc., and Mr. Milos Tomaides, of MMT Environmental, Inc. are recognized for their guidance and technical assistance.

SECTION 1

INTRODUCTION

The processing of sugar beets into refined sugar requires water-supported systems to transport and clean the beets. The quality of this water varies considerably and is affected by the range of conditions that may occur during harvest and storage of the beets. Under normal conditions of harvest and delivery to the processing facility, a once-through transport water would typically have a BOD value in the 200 to 400 mg/l concentration range and a mud tare of 3 to 6 percent of the total weight of the beets. However, when beets are stored into the late winter, the BOD of the transport water can run as high as 25,000 mg/l, and when harvest conditions are adverse, the mud tare can be as much as 20 percent.

Historically, beet sugar processing plants pumped water from a fresh water source and used it for contact condensers on vacuum pans and evaporators. The warm condenser waters were used for transport water and other process requirements and the resulting wastewater was discharged directly to the most readily available surface water. The wastewater volume consisted of the fresh water, the water gained from beets during evaporating and boiling operations, and the pulp press water.

The first major step by the industry toward reducing the BOD loading in beet transport water was to remove pulp press water from the beet transport system and return it to the diffuser. This substantially reduced the BOD of the transport water but did nothing to lower the solids concentration generated by the mud tare. Settling ponds were used to settle out these solids before the supernatant was discharged to a receiving surface water.

As wastewater discharge regulations became more restrictive, holding ponds were introduced into the system to partially stabilize the organic load prior to discharge during spring freshet periods. This innovation generated many spin-off problems of which odor was the most troublesome from the standpoint of technological control and public relations.

Offensive odors have been recognized for some time as a major problem in the beet sugar industry. The odors can arise during and after the processing of the beets. The majority of the odors emanate from the process wastewater and waste sludge lagoons during the spring thaw and the summer months. The high waste load in the lagoons has been, and is currently, the subject of several treatability studies. While a number of these studies have noted the odor problem, very little investigative effort has been directed toward it.

The closed loop system was introduced by the beet sugar industry as a means of promoting better water management through lower fresh water usage. This approach resulted in a water use reduction, but did little to alleviate organic loadings or the odors resulting from the biodegradable constituents of the transport water.

The present study was designed to evaluate a full-scale vacuum filtration system used to dewater sludge from a clarifier in a closed loop water transport system. Of interest were the technical and economic feasibility of this solids handling method and the potential benefits in terms of ultimate disposal of the solids and reduction of associated odors. An ancillary study was carried out to measure and characterize the odors emanating from beet sugar waste storage lagoons.

SECTION 2

CONCLUSIONS

The results of measurements and analyses carried out during the 1976-77 campaign show that the solids handling system was not functioning in the manner supposed at the outset of the study. The underflow solids from the transport water system were largely bypassed at the vacuum filter house (Mud House) and diverted to a storage lagoon, in effect nullifying the purpose of the vacuum filter operation. Instead, waste lime mud, which was to serve as a filter aid, comprised the bulk of the feed to the filters most of the time.

The major reason for the malfunction of the system was the incapacity of the clarifier to adequately thicken the underflow prior to delivery to the vacuum filters. This factor, plus a variety of minor design and control deficiencies, made it virtually impossible to operate the existing system as intended without frequent and severe operating problems and shutdowns.

Because the solids handling system was not functioning properly, the technical and economic feasibility of this approach could not be determined in a meaningful way. Instead, the system components were evaluated and suggestions provided whereby the system could be modified so that the desired results could be obtained.

The results of the odor study demonstrated that various sulfur-containing compounds are responsible for much of the unpleasant odor. Measurements of gas production rates, odor type and concentrations, temperature, and wastewater COD, TDS, and pH provided some preliminary correlations, but it was not possible to pinpoint conditions that could be controlled to effect significant odor reduction.

SECTION 3

RECOMMENDATIONS

Further study of vacuum filtration dewatering of transport water solids is not feasible at the MINN-DAK plant until the solids handling system is modified. An in-depth engineering analysis should be made of the various components discussed in Section 8 so that design criteria can be developed for use in modifying the system.

Evaluation of the odor control benefits of the vacuum filtration approach also is not feasible at the MINN-DAK plant until after the system has been modified and used during one campaign.

SECTION 4

BACKGROUND AND STUDY GOALS

Several research programs have been carried out to solve some of the problems confronting the beet sugar industry but they have been directed mostly at the problem of organic loadings of the wastewater. They have succeeded in determining that the separation and handling of solids is only the first step toward achieving a comprehensive transport water management program.

The composition of the transport water is complex because the water contains not only water-soluble materials but also solid organic material such as beet tissue, leaves, stems, etc., plus the soil particles carried into the system on the beets. The transport water may also contain materials introduced from in-plant operations such as scrub waters from boiler house and pulp drier stack clean-up and routine factory wastewaters. Thus, significant amounts of sulfur, ammonia, foam-breaker compounds, etc. are present to interact with the soil-borne bio-systems that are present in the system.

This complex mixture must be carefully monitored and regulated to prevent acid fermentation with the resultant low pH that can damage equipment and possibly release hydrogen sulfide in factory work areas. Control of transport water pH is accomplished by the addition of lime or a biocide. While this method may give adequate control, it inhibits the reduction of biodegradable materials in the system and thus passes the loading on to subsequent steps in the wastewater treatment system.

Gravity separation of transport water solids is usually included in closed loop systems. Mechanical clarifiers permit the continuous removal of the solids for subsequent processing and disposal. Clarifier underflow contains a mixture of organic and inorganic solids and dissolved materials, of variable pH and solids concentrations, and is inoculated with a variety of microorganisms. Separation of the organic load carried by this solids fraction significantly reduces the BOD and odor potential of the liquid phase.

In addition to the benefits of BOD and odor reduction, a water management program utilizing compact mechanical treatment systems can reduce the land and energy requirements of a large-volume wastewater lagoon system and alleviate the pressure of residential encroachment. These factors gave impetus to EPA support of the beet sugar industry's efforts to conduct studies aimed at developing criteria for the design and construction of treatment facilities to separate the solid and liquid phases of the transport water. An EPA grant (12060 ESC) to conduct a study of the separation, dewatering, and disposal of sugar beet transport water solids was awarded to the American Crystal Sugar Company (ACS) in 1970. The study, conducted at Crookston, Minnesota, dealt with clarification studies of a beet transport water recycle system, a pilot plant feasibility study for dewatering of transport solids by vacuum filtration, and land disposal of the resulting filter cake. (1)

Phase Two of this grant study was to have been an engineering evaluation of a plant-scale dewatering facility. However, due to a number of circumstances, the grant was terminated in 1974 before the second phase began. Some of the findings of the ACS study were later incorporated in the design of the transport water treatment facilities of two recently constructed beet processing plants in the Red River Valley: the American Crystal Sugar Company plant at Hillsboro, and the MINN-DAK Farmers Cooperative plant at Wahpeton, both plants being located in North Dakota.

To evaluate these systems, EPA contacted MINN-DAK late in the summer of 1976 and proposed to have a contractor carry out an evaluation of its transport-water-solids dewatering system and the subsequent management of these dewatered solids. MINN-DAK was receptive to EPA's proposal. As a result, Sverdrup & Parcel, acting as the contractor for EPA, conducted the evaluation during the 1976-77 campaign. Mr. Donald Stewart, of Stewart C & R, Inc., who actively participated in the ACS study, agreed to act as a beet-sugar-processing environmental consultant for the project. The study was authorized on October 13, 1976. The data collection for the campaign period took place between November 14, 1976 and January 13, 1977. This was followed by a post-campaign data collection period from April to July, 1977.

This study was aimed at determining the technological feasibility of vacuum filtration as an effective method to dewater beet transport water solids, including the economic and environmental aspects of the ultimate disposal of the resulting cake. With this in mind, the objectives of the study were as follows:

1. Evaluate a full-scale sugar beet transport-water-solids vacuum filtration dewatering process for operational reliability and efficiency.

2. Determine the economics of the dewatering process.

3. Evaluate the adequacy of the method of ultimate disposal of the dewatered solids.

4. Determine the economics of the ultimate disposal method as affected by current and proposed regulations.

The site of this study was the MINN-DAK Farmers Cooperative located in Wahpeton, North Dakota, in the Red River Valley, the nation's sugar beet bowl (1). The cooperative was organized in 1972 and the factory was completed in 1974 as a turn-key project by the West German firm of BMA Machinery and Equipment Company. The general contractor for the construction was Krause Anderson of Minneapolis, Minnesota. Precampaign statistics for

1975-76 show that the cooperative had 270 stockholders and that it processed beets grown by over 300 growers in an eight-county, two-state area comprising over 21,000 hectares (52,000 acres). The plant, which was valued in the fall of 1975 at about $31,600,000, has a beet slicing capacity of 4,535 metric tons (5,000 tons) per day (2). The plant does not incorporate the Steffen process.

Dry growing conditions in the summer and fall of 1976 produced a low yield of 22.5 metric tons per hectare (10 tons per acre) and a short campaign. The growing area's precipitation was approximately 25 cm (10 in) below normal for the period between May and August, as reported by Gordon Rudolph in the August, 1976 edition of the Reporter, MINN-DAK's official publication (3). The 1976-77 campaign, MINN-DAK's third, was officially started on September 27, 1976, and the last slicing day was January 21, 1977, for a total of 117 operating days. Final campaign operating figures were as follows:

Beets sliced:	409,776 metric tons (451,765 tons)
Sugar produced:	53,953 metric tons (59,484 tons)
Pellets produced:	25,001 metric tons (27,564 tons)
Molasses produced:	27,610 metric tons (30,441 tons)
Dirt tare on beets:	3.3% dry solids by weight

Although the cooperative had not developed a program to provide directly for the ultimate disposal of solids, MINN-DAK's agreement with the growers includes a provision whereby beet cultivation is done on a three-year crop rotation basis, i.e., a beet-growing parcel cannot be re-used for cultivation of beets until two years have elapsed. This is done to maintain the nutritional stability of the soil and to prevent the spread of disease. MINN-DAK indicated that the growers are also required, under this agreement, to take a portion of the clarifier underflow solids in proportion to the quantity of beets delivered the previous season. The growers may, at their discretion, dispose of this material by spreading it on the fields they cultivate, stockpiling it, or taking it to a sanitary landfill. The beet growers are reluctant to use the sludge on their land, however, for fear of damaging their crops. Other disposal means are not always available, and MINN-DAK is seeking satisfactory alternatives for ultimate disposal of solids.

A sampling and analytical program for the study was designed. Four streams were selected for analysis to determine the effectiveness of the dewatering process: the clarifier underflow containing the transport water solids; the lime mud used as the filtering aid; the filtrate, or liquid fraction, from the vacuum filters; and the filter cake, or solid fraction.

The analytical program was divided into two data collecting periods, dictated by both operating and climatic conditions, as follows: a November to January campaign period to evaluate the operation of the vacuum filtration station with respect to process effectiveness and equipment reliability; and an April to July post-campaign period to evaluate the results of the process with respect to odor and gas production that took place during the warmer months of the year.

This report presents the results of the study, including descriptions of systems and operations, data collected from the sampling and analytical programs during both the campaign and post-campaign periods, and discussion and interpretation of the findings. Proposed modifications to the system are also presented.

SECTION 5

SYSTEM DESCRIPTION

This section describes MINN-DAK's transport water system, the primary treatment clarifier, and the vacuum filtration units that dewater the clarifier underflow. The sludge storage lagoons are also described. Pertinent activities by MINN-DAK prior to the start of the study are also outlined.

TRANSPORT WATER SYSTEM

MINN-DAK Farmers Cooperative operates a beet transport water recycle system that includes primary treatment (clarification) to remove coarse and settleable solids and vacuum filtration for dewatering the solids removed in clarification. Lagoons are provided for the storage of both the filtered solids (filter cake) and the unfiltered (bypassed) clarifier underflow solids. A schematic process flow diagram of this system is shown in Figure 1.

Beets are dumped into a wet hopper at the head of the beet flume. Water, serving as the transport medium, pushes the beets into the beet flume, and down to the next processing station. The flow of beets is controlled by a beet flume control wheel, the speed of which determines the quantity of beets to be processed. Leaves and weeds, still carried along with the beets in the flume, are separated from the beets in a trash catcher and eventually hauled off the site by truck. Some beets are also removed by the trash catcher and are hand-picked and returned to the flume.

Rocks and coarse sand are separated from the beets by a rock catcher prior to the beets' discharge, via a lifting wheel, into the beet washer. At the beet washing station, intensive agitation and simultaneous addition of fresh water remove soil particles still adhering to the beets. After the washing procedure, the beets are sprayed with fresh water on a roller spray table and arrive at the picking table where any remaining leaves, rocks, or other foreign matter are removed manually. The washed beets are transported through an ascending belt conveyor to the slicing station and on to the extraction process.

The flume water containing the soil, tailings, and other solids is pumped to vibrating screens where coarse solids are screened out. This water then flows by gravity to a grit chamber where sand and other heavy particles are removed. After the grit chamber, about one-third of the water volume is pumped to the pulp drier heat exchanger to raise the temperature of the transport water. The transport water then flows by gravity to a sump

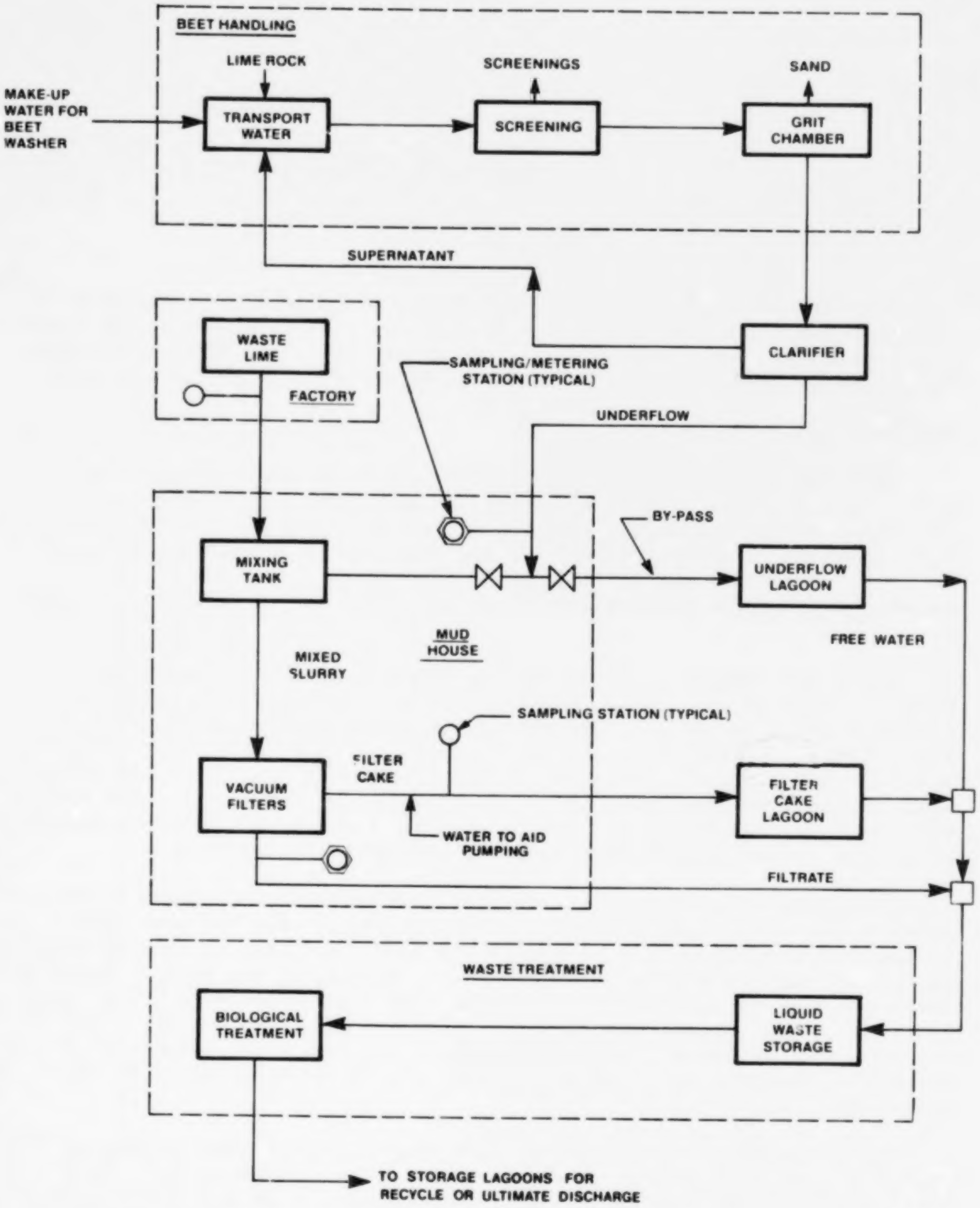

BEET HANDLING
LIME ROCK
SCREENINGS
SAND
MAKE-UP WATER FOR BEET WASHER
TRANSPORT WATER
SCREENING
GRIT CHAMBER
SUPERNATANT
WASTE LIME
FACTORY
CLARIFIER
SAMPLING/METERING STATION (TYPICAL)
UNDERFLOW
BY-PASS
MIXING TANK
UNDERFLOW LAGOON
MUD HOUSE
FREE WATER
MIXED SLURRY
SAMPLING STATION (TYPICAL)
FILTER CAKE
VACUUM FILTERS
FILTER CAKE LAGOON
WATER TO AID PUMPING
FILTRATE
WASTE TREATMENT
BIOLOGICAL TREATMENT
LIQUID WASTE STORAGE
TO STORAGE LAGOONS FOR RECYCLE OR ULTIMATE DISCHARGE

Figure 1. Transport water system process schematic.

where it is pumped at a rate of 34,440 cu m/day (6,320 gpm) to the clarifier to begin a new cycle.

Primary Treatment

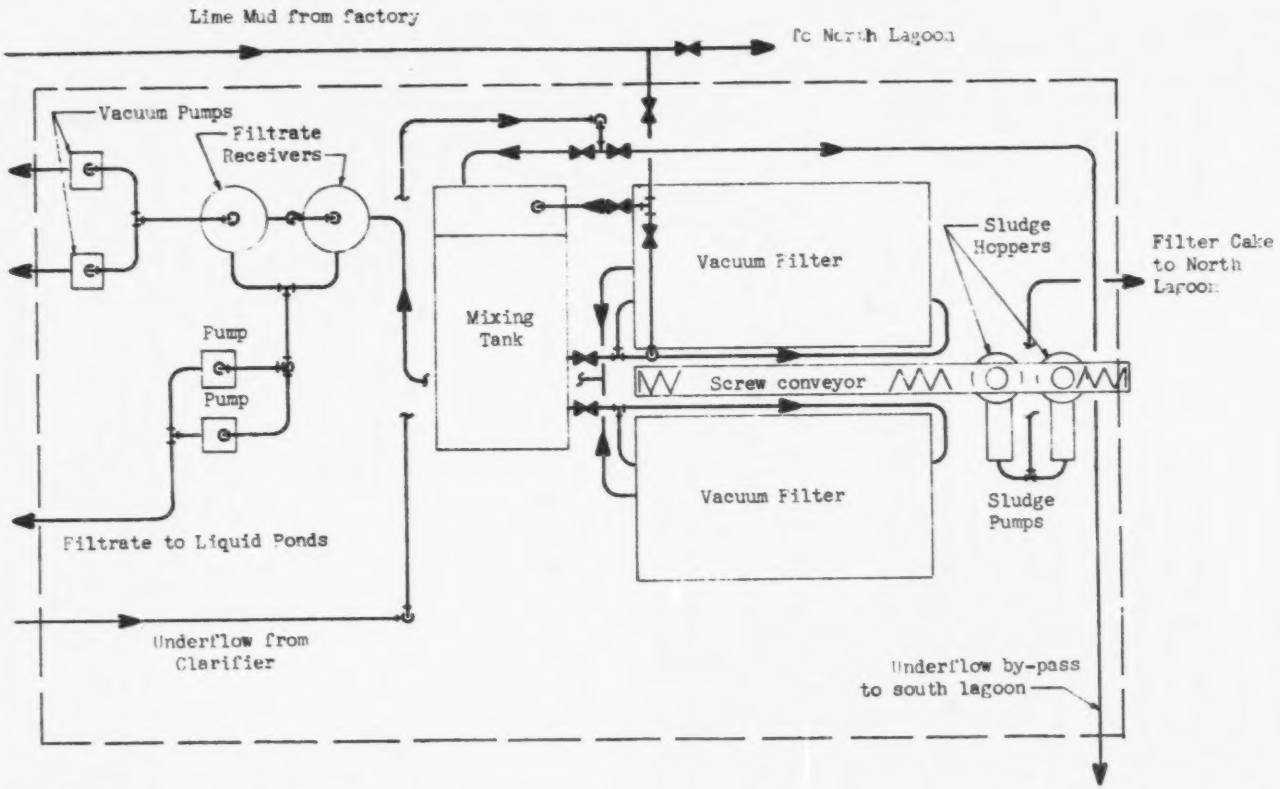
Clarification takes place in a shallow, circular, reinforced concrete basin equipped with a traveling bridge. The bridge rotates around the basin by means of a motorized wheel traveling on top of the interior weir wall. The bridge is equipped with a motorized screw auger to break up ice, spray jets to break up foam, and sludge squeegees, supported by vertical pickets, that push the sludge to a concentric collecting trough located at about the one-third point from the center. Sludge is lifted out of the clarifier by means of a variable-speed pump through an adjustable snout that traverses the trough at actual pumping rates ranging from 760 to 1,250 cu m/day (140 to 230 gpm), depending on sludge consistency. The clarifier supernatant overflows through inclined and submerged ports within the interior weir wall into a peripheral weir trough, and from there it flows by gravity to the beet transport flume.

The clarifier basin has an inside diameter of 44 meters (144.3 ft), a sidewater depth of 1.25 meters (4.1 ft), and a bottom slope, from the inner wall down to the sludge trough, of about 1:80. The above dimensions yield a surface area of 1,520 sq m (16,360 sq ft) and a volume of 1,900 cu m (67,080 cu ft). Weir loading is 249 cu m/m (20,000 gpd/ft). The hydraulic detention time, at an influent rate of 34,440 cu m/day (6,320 gpm), is 80 minutes. The overflow rate of the basin, at the influent flow rate, is 22.66 cu m/day/sq m (560 gpd/sq ft). At an assumed soil tare of 5 percent, and a plant production capacity of 4,535 metric tons (5,000 tons) of beets per day, the dry solids loading on this basin becomes 149 kg/sq m/day (30.6 lb/sq ft/day).

Vacuum Filtration

Vacuum filtration takes place at the Mud House, schematically illustrated in Figure 2. The clarifier underflow is pumped through a 10.2 cm (4-inch) pipeline to the Mud House where the flow is directed, by means of gate valves, to either the mixing tank or to the underflow storage lagoon. Lime mud from the factory, used as an aid to clarifier underflow filtration, is pumped to the mixing tank or directly to the north lagoon. (See Fig. 2). The lime mud is the residue of the juice purification process. The milk of lime- and carbon dioxide-treated juice is heated and thickened and the resulting mud concentrate, containing calcium carbonate and removed non-sugars, is vacuum-filtered at the factory. The filter cake (lime) is then slurried and pumped to the Mud House through a 15.2 cm (6-inch) diameter elevated insulated pipeline at a temperature of between 40° and 55°C (104° to 131°F).

The mixing tank is a cylindrical-bottomed, open-topped, double-compartment, welded-steel tank approximately 5 m long and 1.6 m wide (16.5 ft. by 5.3 ft) and about 3.0 m (10 ft) high. The tank is equipped with a motorized, rotating helical coil to mix the tank contents. Both the clarifier underflow and the lime mud influent pipes enter the tank through an end


Lime Mud from factory
To North Lagoon
Vacuum Pumps
Filtrate Receivers
Pump
Pump
Filtrate to Liquid Ponds
Underflow from Clarifier
Mixing Tank
Vacuum Filter
Screw conveyor
Vacuum Filter
Sludge Hoppers
Sludge Pumps
Filter Cake to North Lagoon
Underflow by-pass to south lagoon

NOTES:

Only key equipment and piping are shown.
Some piping shown schematically rather than actual layout to enhance clarity.

Figure 2. Mud house layout: vacuum filtration system.

compartment that comprises about one-fourth of the tank. The tank contents flow by gravity to the vacuum filters through a 20.3 cm (8-inch) pipe located at the bottom of the tank. The mixing tank is also equipped with a clear plastic tube that serves as a visual level indicator for the operators and with an overflow pipe that discharges into a sump below. This sump also collects filter wash water and general clean-up flows within the Mud House.

Filtration is carried out on two BMA vacuum drum filters, each having a filter area of 63.8 sq m (687 sq ft), a diameter of 3.6 m (11.7 ft), and a length of 5.7 m (18.7 ft). Each filter consists of a cylindrical drum rotating in a pan filled with the sludge slurry. The drum, made of perforated steel plate, is covered by a filter cloth (Filter's Company, Inc., No. 06859) secured to the drum by wire bands spaced about 9 cm (3.5 inches) apart. As the drum rotates, a vacuum is applied between the drum deck and the filter medium. This causes water to be extracted and sludge solids to be retained on the cloth. The vacuum filters typically operate with a vacuum of 127 to 254 mm (5 to 10 inches) of mercury, and at a rotational speed of 0.4 revolutions per minute. The vacuum filter main drive is powered by a 14.9 kw (20 hp) motor. Each filter is also equipped with a 7.5 kw (10 hp) motor agitator to keep solids in suspension and a 1.5 kw (2 hp) pump and piping to remove sand and other heavy solids that settle in the pan to the top of the drum as it rotates.

Vacuum is provided by two Nash 200-2, 93.2 kw (125 hp) motor, vacuum pumps. The filtrate is drawn to two vertical receiver tanks connected in series where the level is maintained to provide separation of the air and liquid phases. A pneumatic level controller actuates the operator of a butterfly valve to regulate the flow out of the receivers. The filtrate is pumped out of the Mud House through a 15.2 cm (6-inch) pipeline and is discharged into liquid waste storage ponds. The filtrate can also be returned to the clarifier. Table 1 shows design lime mud and filter cake data, adjusted to achieve a balance.

As the drum completes its rotation and nears the point of discharge, the cake is lifted from the cloth with air supplied by two Cycle Blower Compressor blowers, 7CDL 17 H, Gardner Denver Co., 55.5 cu m/min (1960 cfm), 1.27 kg/sq cm (18 psig), 360 rpm, 55.9 kw (75 hp) motor. Then, with the aid of a blade, the cake is removed from the drum and dropped into a screw conveyor. Water is added to the cake for better pumping. The screw conveyor moves the sludge toward the hoppers feeding two positive displacement sludge pumps. The hydraulically powered dual-chamber Schwing PSP 17 pumps have a volumetric displacement per chamber of 0.017 cu m (0.62 cu ft) at maximum stroke. At an average rate of 13,260 strokes per day, and assuming a 75 percent effective stroke, each pump is capable of delivering about 335 cu m (90,000 gal) of sludge per day.

The hydraulic system is powered by a 93.2 kw (125 hp) motor. The sludge is pumped to the sludge storage lagoon through an above-ground pipeline made of standard length sections of 15.2 cm (6-inch) carbon steel pipe coupled with Victaulic fittings. At the end of the pipeline, there is a derrick-like boom that projects out over the lagoon to distribute the sludge.

TABLE 1. DESIGN LOADINGS FOR VACUUM FILTRATION PROCESS

INPUT/OUTPUT	Mass kkg/day	Volume cu m/day	Percent Weight	Density kkg/cu m
Clarifier underflow	2,840	2,760	100	1.03
Solids	230	150	8	1.58
Water	2,610	2,610	92	1.00
Lime mud	690	490	100	1.40
Solids	330	130	48	2.47
Water	360	360	52	1.00
TOTAL INPUT	3,530	3,250	--	1.09
Filter cake	1,120	840	100	1.33
Clarifier solids	230	150	20	1.58
Lime mud solids	330	130	30	2.47
Water	560	560	50	1.00
Filtrate *	2,410	2,410	100	1.00
TOTAL OUTPUT	3,520	3,250	--	--

* Assumes no significant solids content

The wash water from washing the filters and clean-up of the Mud House collects in a floor drain that discharges into a sump from where it is pumped to the liquid storage ponds. Filter wash water was formerly recycled to the mixing tank. This practice was stopped, however, when it was discovered that oily and soapy materials in the wash water caused blinding of the filter media.

Lagoons

A plot of the layout of the sludge storage lagoons and the Mud House is shown in Figure 3. The 4.5 ha (11 acres), L-shaped, south lagoon is where the bypassed clarifier underflow is retained. The rectangular north lagoon, also having a surface area of 4.5 ha (11 acres), is where the filtered sludge cake is stored. A drainage ditch around three sides of the north lagoon channels free water from both lagoons to a point near the Mud House. The free water is pumped to one of the wastewater storage lagoons by means of submersible pumps lowered into the dead end of the ditch near the Mud House. The free water is mixed with the filtrate and other factory-generated liquid wastes. All of these wastes are stored for the winter, treated during the intercampaign period, and either discharged or stored for recycling in the industrial water supply system. The sludge storage lagoons were designed to be cleaned every two or three years.

ACTIVITIES PRIOR TO STUDY

During each intercampaign period, in preparation for the next processing season, the plant personnel carry out the necessary maintenance and overhaul of equipment to be prepared for the breakneck pace that allows for few interruptions once the sugar processing campaign has started. Major modifications, alterations, and additions to existing facilities are usually made between February and September. During this period, treatment of wastewater accumulated during the campaign is also carried out.

During the intercampaign period of 1976, the two sludge storage lagoons were cleaned of the material accumulated during the previous two campaigns, and extensive repairs were made on the vacuum filters and the sludge pumps at the Mud House. The Mud House equipment repairs were performed by MINN-DAK's operating and maintenance personnel. The job of removing the sludge from the lagoons was awarded to a contractor. The contractor brought in bulldozers, trucks, and other earth moving equipment to perform this work.

Independently of this study, and on its own initiative, MINN-DAK entered into an agreement with a neighboring farmer to have some of the filter cake lagoon contents spread and mixed on his farmland for the purpose of determining the feasibility of this disposal method. To this end, filter cake sludge was applied in layers 7.6 and 12.7 cm (3 and 5 in) thick to two 0.4 hectare (one-acre) parcels. The sludge was disked and mixed with the soil and the entire field was planted with wheat. Another portion of the filter cake sludge was used to build up the lagoon dikes and the balance was hauled by the contractor to a nearby trailer park construction site for use as fill material.

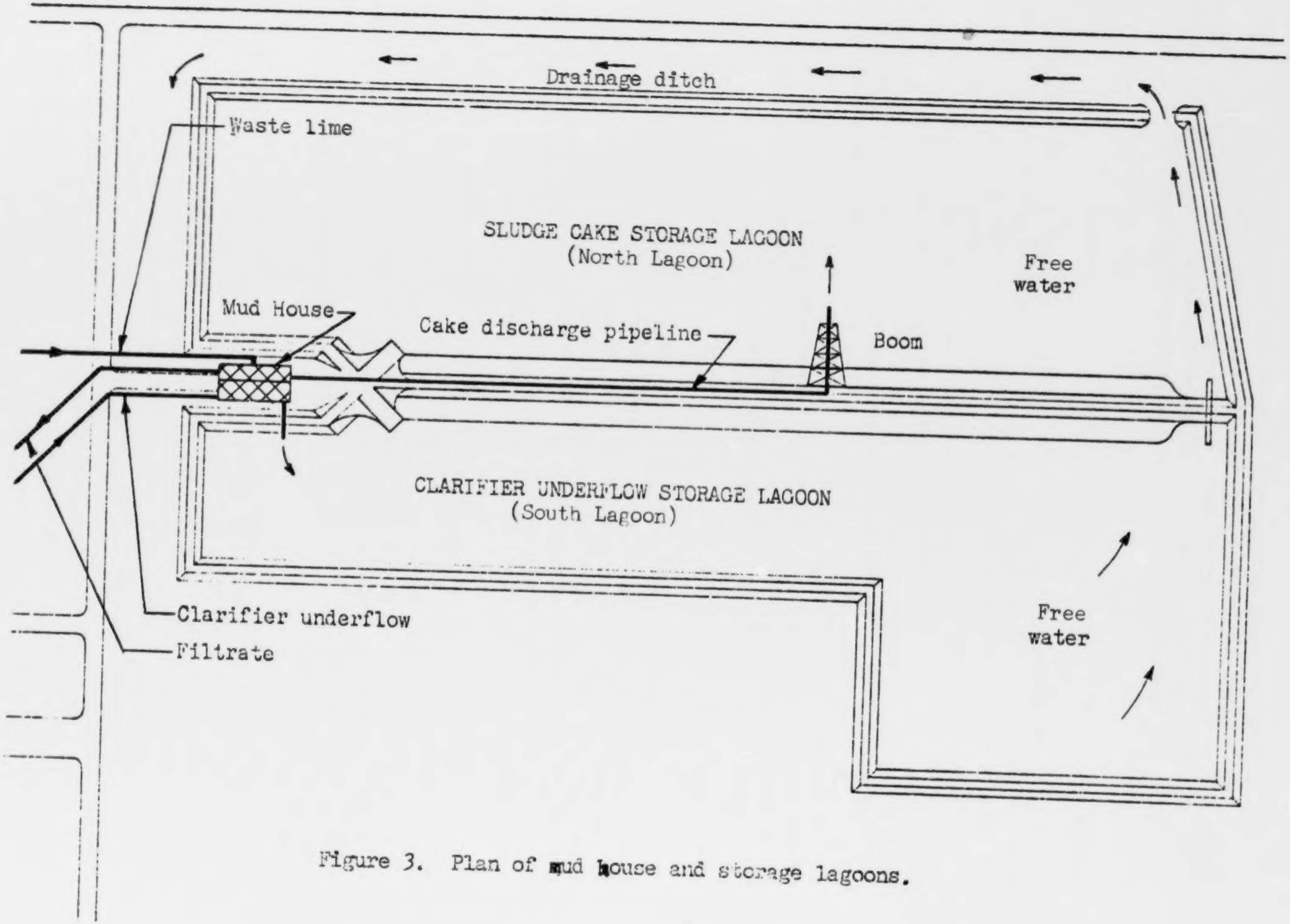

Drainage ditch
Waste lime
SLUDGE CAKE STORAGE LAGOON
(North Lagoon)
Free water
Mud House
Cake discharge pipeline
Boom
CLARIFIER UNDERFLOW STORAGE LAGOON
(South Lagoon)
Free water
Clarifier underflow
Filtrate

Figure 3. Plan of mud house and storage lagoons.

The Mud House equipment repairs consisted mainly of replacing the vacuum filter agitators and installing a 20.3-cm (8-in) pipeline with a quick-action valve for periodic discharge of sand and gravel accumulating in the bottom of the filter pans to the filter cake lagoon. The agitators were replaced because the original drive arms were not strong enough and were bent by the sand load in the underflow from the clarifier. The other major repair of Mud House equipment included rebuilding of the filter cake pump cylinders, part of the normal maintenance for these pumps.

SECTION 6

STUDY PROCEDURES

This section presents the details of the sampling program and analytical methods used to characterize the two input and two output streams at the vacuum filters. The flow monitoring procedures for these streams are also outlined. The third part of this section describes the methodology of the post-campaign study to measure the intensity and production rate and determine the chemical composition of the odorous gases generated at the sludge and liquid waste storage ponds.

ANALYTICAL PROGRAM

A Monday through Saturday sampling and monitoring program was instituted. The parameters and streams sampled and analyzed are presented in Table 2. The sampling stations are shown in Figure 1. An operating log was also kept (Appendix B) to provide data for use in evaluating the reliability of the process. Data were collected in two separate groups: 1) 22-hour composite grab samples collected up through January 6, 1977; and 2) data from 8-hour composite grab samples collected after that date. Thus, typical around-the-clock operation of the Mud House, as exemplified by the first group of data, can be compared with a closely controlled and monitored period of operation that was aimed at optimizing filtration of the clarifier underflow, as exemplified by the second group. This special monitoring period is described in detail in Section 7.

For the 22-hour sampling, equal-volume aliquots were collected at every odd-numbered hour and composited into daily samples. The first sample aliquot was collected at 9:00 a.m. and the last one at 7:00 a.m. of the following day. With the exception of the lime mud sample, which was collected at the factory by laboratory personnel, all samples were collected at the Mud House by the operating personnel. The Mud House operators were also asked to record, concurrently with collection of the samples, sampling and operating equipment information in the log. The sampling instructions are provided in Appendix D.

Self-cleaning piston type Strahman sampling valves were purchased and installed on the clarifier underflow and the filter cake pipelines. The filtrate, because of its low solids content, did not require this type of valve, and the valve in place was used to obtain the samples. The lime mud pipeline at the factory already had a self-cleaning sampling valve.

Each of the filtrate and the clarifier underflow sampling stations was furnished with a stainless steel dial thermometer, a waste bucket, a col-

TABLE 2. SAMPLING AND ANALYTICAL SCHEDULE

ANALYSIS	SAMPLING POINT *				
	Clarifier Underflow	Lime Mud	Filtrate	Filter Cake	Cake Storage Area
COD Total	1	1	1	1	
COD Soluble	2	2	2	2	
Ca Total	1	1	1	1	
Ca Soluble	1	1	1	1	
Temperature	3	3	3		
Total Solids	1	1	1	1	1
Volatile Solids	1		1	2	
pH	1		1		
Bulk Density	1	1		1	1
Odor Number	4		4#		4
Viscosity	5	5		5	5

* **KEY**

1 Daily: 6 days/week
2 Weekly
3 Instantaneous on each grab sample, as appropriate
4 Post-campaign
5 Test to be conducted on equipment or time available basis; however, at least 3 analyses per sampling point were conducted.

# Odor number was measured on samples taken from the wastewater lagoons. It was not possible to separate the filtrate from other plant wastes.

lecting bucket, a wide-mouth sample container, and a ladle to stir and measure the sample aliquots. The lime mud and the cake storage sampling stations had built-in sample collecting buckets, and sample aliquots were measured with a spoon and placed into wide-mouthed sample containers. The temperature of the lime mud was measured at the laboratory near the collection point. The filter cake samples were obtained by reaching down from the platform into the cake discharge area of the filter with a long-handled ladle. The samples were then placed in wide-mouthed containers. All containers remained tightly capped between collections.

Every morning, at the beginning of the first shift, the equal-volume composite samples and the daily log sheet were taken to the factory laboratory. MINN-DAK's personnel reviewed the log sheets and entered the lime mud temperatures recorded by the laboratory technicians. The samples, including the lime mud sample collected at the factory, were analyzed during the second shift to avoid conflict with the factory's main laboratory work carried out during the first shift. Consequently, sample analyses were started nine to ten hours after the last aliquot was added to each composite sample. Although pH was one of the parameters measured, the delay between sample collection and analysis rendered composite sample pH values unreliable due to bacterial action. Only instantaneously measured pH values of grab samples (shown in Table A-3 of the Appendix) were used in the analysis of results. The samples were not preserved.

A list of references for the analytical methods employed is provided in Appendix C. For quality control purposes, one set of samples was analyzed in duplicate each week during the sampling program. In addition, a standard solution of potassium biphthalate was analyzed daily with each set of COD samples. Determinations of bulk density were made in triplicate. Sets of EPA Quality Control Reference Samples were analyzed by the technicians at MINN-DAK and at the Sverdrup & Parcel Water Laboratory. The results of these analyses are also in Appendix C.

FLOW MONITORING

A survey of the dewatering facilities, conducted during the preliminary stages of the project, revealed that there were inadequate provisions for flow measurement and that a number of devices had to be installed. By the time the project was authorized, the campaign was already under way, and flow meters had to be specified, purchased, and installed quickly. Both magnetic and ultrasonic flow meters were investigated. Magnetic flow meters have been successfully used to measure the flow of slurries, but ultrasonic flow meters have only recently appeared on the market. Time and installation requirements, however, dictated the use of the latter. They could be delivered in a much shorter time and no process interruptions were involved in their installation.

Clampitron flow meters (Controlotron Corp.) were ordered and liquid samples of the clarifier underflow, filtrate, and lime mud were shipped to the meter manufacturer for testing and calibration. The manufacturer's tests showed that ultrasonic flow meters could be used for the first two waste streams, but not with the lime mud flow because of its high solids concentration. Since ultrasonic meters could not be used, the volume of lime mud delivered daily to the Mud House was calculated using an empirical equation developed by MINN-DAK personnel. The equation states that the mass of CaO generated by carbonation per day (available from factory production records) divided by the concentration of CaO in the lime mud yields the volume of lime mud per day.

A series of measurements relating flow rate to the percent motor load of the pump was made to determine the amount of underflow pumped out of the clarifier. With the percent motor load of the pump set at different positions, all within the normal operating range, the rise in level was timed at the mixing tank. A curve was then plotted and flow was calculated based on the average pump motor load setting for that day. The clarifier operator recorded the pump setting every hour.

Late in the study, it was demonstrated that within the normal range of clarifier pump settings, it was unnecessary to close the west valve leading to the mixing tank to prevent underflow from entering the tank. All that was needed to direct flow, either to the mixing tank or bypass to the lagoon, was to open or close the east valve. A series of measurements was then made to relate the amount of clarifier underflow entering the mixing tank to the setting of the east valve. With the clarifier pump set at a given percent load, the east valve was slowly closed until underflow began to enter the mixing tank, at which point the length of the valve stem outside the valve body was measured. The valve was then closed in 6 mm (1/4 inch) increments, the level-of-rise versus time readings were recorded, and the flow rate for each adjustment was calculated. Table A-2 of the Appendix, relating degree of valve opening and percent motor load to flow rate, was prepared for the benefit of the operators. The problem remained of not knowing the percent motor load of the clarifier pump at any given time.

Two methods were considered for measuring the amount of filter cake produced at the Mud House. The first method involved calculating the volume of the cake produced per unit of time by multiplying the speed and the width of the drum by the measured thickness of the cake. The second method involved calculating the amount of cake produced using the volumetric displacement of the pumps that transport the cake to the north lagoon. Since the sludge volume calculated by this method would include the water added to the cake to improve its flow characteristics, the volume was adjusted by multiplying by the ratio of the moisture content of the "dry" filter cake to that of storage lagoon samples.

Mechanical counters were installed to record the number of pump strokes. They started to malfunction soon after installation. The warm humid Mud House environment caused condensation on the inside of the counter windows. This was resolved by removing the windows and covering the openings with plastic bottles to protect them from direct splashing.

ODOR STUDY

The odor study was carried out during the post-campaign period and consisted of field collection of gas samples from the filter cake storage lagoon (lime pond), the clarifier underflow storage lagoon (mud pond), and one of five liquid storage ponds containing a substantial amount of filtrate (wastewater pond). The liquid storage ponds receive, in addition to the filtrate, factory wastewaters discharged as a result of the production process and such miscellaneous wastewaters as filter wash water, Mud House and other factory clean-up water, free standing water draining from the lime and mud ponds, etc. Gas samples from each of these three waste storage ponds were analyzed to determine odor intensity, gas production rate, and the chemical composition of the gas constituents.

Odor Intensity

In order to assign an accurate measure of intensity to the odors arising from the various ponds, the following steps were taken: a) a collection device was installed that permitted capture of pond off-gases, yet did not interfere with the natural behavior of the pond in the area of the collector; b) a unit of odor measurement that was scientifically sound and that could be related to existing governmental regulations was agreed upon; and c) a means of odor measurement that would produce a high degree of accuracy and repeatability was developed.

Floating tents were designed and built, as shown in Figure 4, for each of the three waste storage ponds to be tested. The design permits the tents to float freely on the pond and also to penetrate the liquid surface sufficiently to prevent outside air from entering at the base. Each tent was tethered at one corner with a long rope to an anchor to aid in retrieving it and to prevent it from becoming beached on shore. Vents in the top served as gas relief ports and a hole near the base served as the sampling port. The tents were periodically repositioned to: 1) avoid algae build-up resulting from a greenhouse effect; and 2) restore them to their original positions when moved by the wind.

Both the odor concentration unit and the odor measurement methods used in this study are covered in the Minnesota Pollution Control Regulation (4), one of the most thorough odor regulations in the United States. The regulation states that "odor concentration unit shall mean the number of standard cubic feet of odor-free air needed to dilute each cubic foot of contaminated air so that at least 50 percent of the odor concentration test panel does not detect any odor in the diluted mixture." The regulation further outlines the procedures to be used for obtaining odor samples and presenting the samples to a test panel.

The program called for the collection and analysis of samples at approximately two-week intervals to obtain a profile of activity as affected by changes in temperature. Samples were drawn from the floating tents through a short length of 6 mm (1/4-inch) Teflon tubing connected to the port at the base of the tent and a two-liter Teflon sample bag. The samples were usually drawn between 8 and 9 a.m. in order to facilitate same-day analysis. Odor concentrations were determined according to ASTM D1391-57(5). The panel testing procedure used was the method described by D. M. Benforado, et al (6). A six-member panel of odor testers evaluated the samples. Panel

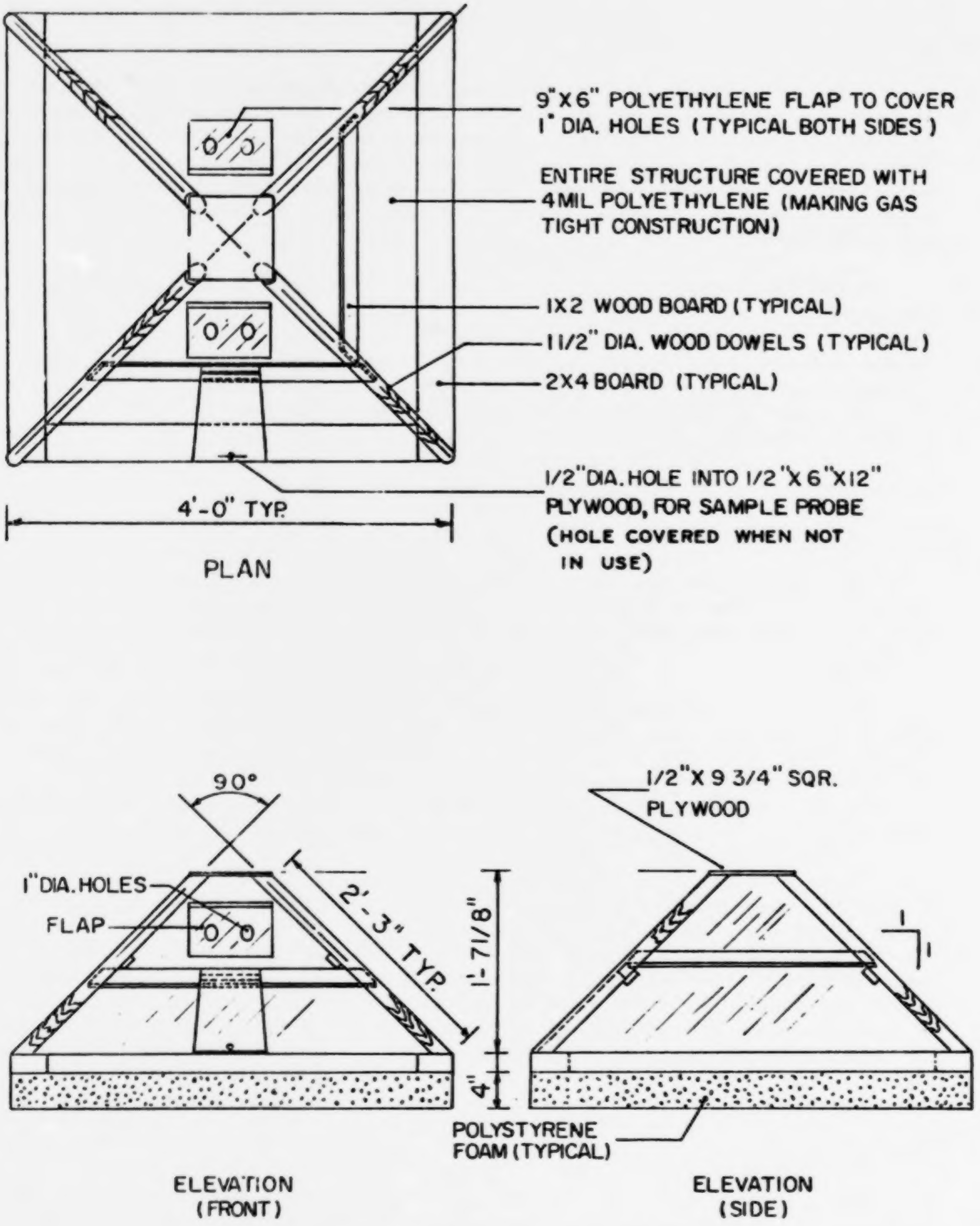

9"X6" POLYETHYLENE FLAP TO COVER 1" DIA. HOLES (TYPICAL BOTH SIDES)
ENTIRE STRUCTURE COVERED WITH 4MIL POLYETHYLENE (MAKING GAS TIGHT CONSTRUCTION)
1X2 WOOD BOARD (TYPICAL)
11/2" DIA. WOOD DOWELS (TYPICAL)
2X4 BOARD (TYPICAL)
1/2" DIA. HOLE INTO 1/2"X6"X12" PLYWOOD, FOR SAMPLE PROBE (HOLE COVERED WHEN NOT IN USE)
4'-0" TYP.
PLAN
90°
1" DIA. HOLES
FLAP
2'-3" TYP.
1'-71/8"
4"
1/2"X9 3/4" SQR. PLYWOOD
1
1
POLYSTYRENE FOAM (TYPICAL)
ELEVATION (FRONT)
ELEVATION (SIDE)

Figure 4. Floating gas collector.

members were first familiarized with the type of odor from each source with samples of undiluted gas.

Various dilutions of the grab samples were prepared and presented to the members of the odor panel in 100-ml syringes. The panel members smelled the samples and recorded whether or not they detected an odor. After the sample was tested, the panel member flushed the syringes with room air until satisfied that no odor remained. Brief rest periods were provided during which the panelists breathed filtered purified air to avoid olfactory fatigue and retain sensitivity.

After the evaluation of a given sample, responses were tabulated and the percent of positive responses plotted against dilution on log-normal probability graph paper. The best straight line was drawn through the points and the dilution corresponding to 50 percent was taken as the odor concentration in odor units per standard cubic foot (ou/cf). In addition to the test panel's determination of the odor concentration, the panel was pooled to interpret odor quality. Such terms as "pig pen", "musty", "stale river", etc., in combination with the numerical listing of odor concentration units, provided a meaningful qualitative relationship.

Off-Gas Production

The lagoons are area sources due to their large surface area and groundline profile. The rate of gas emission from such a source and the concentration of constituents must be known in order to properly assess the magnitude of the source.

Criteria for general gas collection devices were as follows. The device had to: a) avoid interference with the natural biochemical action in the ponds; b) adjust to fluctuating pond levels; c) be suitable for dewatered and sloping pond surfaces; d) restrict entrance of outside air or release of trapped gases to the atmosphere; e) provide a means of measuring and recording the amount of off-gases generated; and f) be portable.

These criteria were met with an equipment arrangement as shown in Figure 5. The equipment was installed prior to the spring thaw by cutting a hole in the ice. Initially, gas production measurements were made on a random basis; later, a regular schedule of daily examination and weekly measurements was established. The gas sampling bag was taken to the lab where gas volume was determined by fluid displacement. Before reinstallation of the bag, the collecting carboy was raised free of the pond surface to permit displacement of accumulated surface material. The carboy was then reset in its former position and the evacuated bag reconnected. The system was disconnected for less than one hour during this procedure.

Odor Constituents

While the determination of the concentration of an odor quantifies its presence, it reveals nothing of its chemical nature. It is obvious that certain chemical compounds are responsible, either singularly or in combination, for the offensive nature of beet sugar waste pond off-gases.

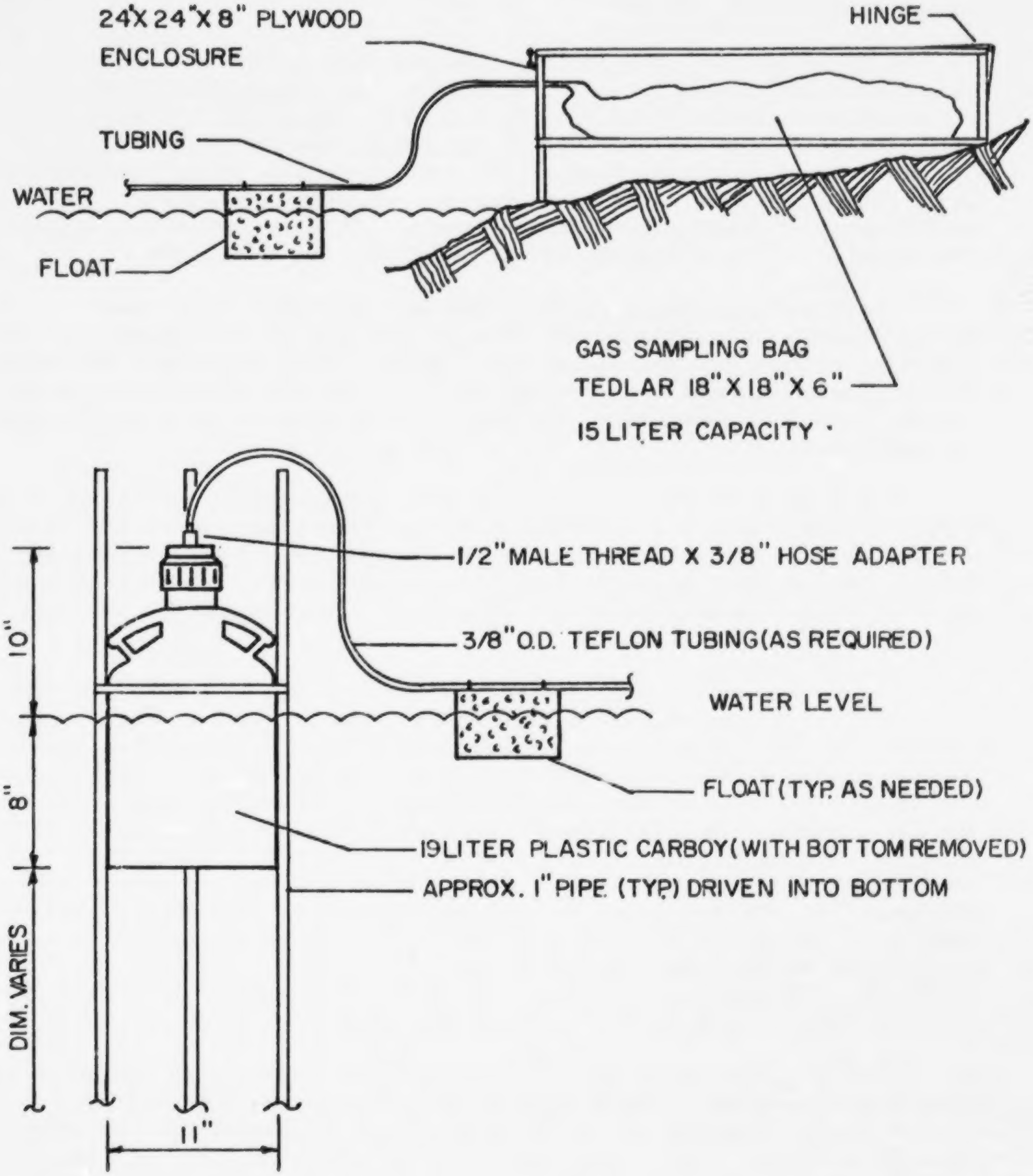

24"X 24"X 8" PLYWOOD ENCLOSURE
HINGE
TUBING
WATER
FLOAT
GAS SAMPLING BAG
TEDLAR 18"X 18"X 6"
15 LITER CAPACITY
1/2" MALE THREAD X 3/8" HOSE ADAPTER
3/8" O.D. TEFLON TUBING (AS REQUIRED)
WATER LEVEL
FLOAT (TYP. AS NEEDED)
19 LITER PLASTIC CARBOY (WITH BOTTOM REMOVED)
APPROX. 1" PIPE (TYP.) DRIVEN INTO BOTTOM
10"
8"
DIM. VARIES
11"

Figure 5. Gas production sampler.

An effort was made as a part of this study to ascertain what these chemical constituents are.

It is known that certain compounds are detected by the human nose at exceedingly low concentrations. Therefore, the investigation and identification of the chemical constituents had to be intensive. In order to avoid analyzing for every gas constituent that might have been present, a first cut was made by analyzing some of the initial samples by gas chromatography (GC). The GC scan revealed what chemical compounds were present, and to a certain degree, their concentration levels. It also detected a number of compounds below the threshold level needed for identification.

Subsequent gas sample analyses demonstrated that those chemical compounds readily identified by the GC scan were not at concentrations high enough to produce the associated odor levels. This reinforced the suspicion that odorous compounds were present at below the identification threshold levels for the GC instrument, but above the threshold levels detectable by the human nose.

It was decided that concentrated odor gas samples should be obtained in order to permit more positive detection and identification of the chemical constituents of the gas through gas chromatography and mass spectrometry. Several methods for obtaining concentrated gas samples are available and two were selected to provide a margin of safety; condensation and adsorption on activated charcoal.

Preparation of the condensation freeze trap was in accordance with ASTM D1605-60(7). A literature check provided a partial list of the chemical constituents likely to be present and responsible for the offensive odors. A check of their freezing points indicated that all could be readily frozen out of an air stream at the -78.5°C temperature provided by an acetone and dry ice mixture. The glass vacuum trap was suspended in an insulated vacuum flask containing the dry ice and acetone mixture and 4 liters/minute (0.1413 cfm) of gas from the collection tent was drawn through the vacuum tube for one hour. At the conclusion of the sampling period, the ends of the vacuum tube were sealed and the tube with the frozen sample was placed in an insulated chest at the same temperature for shipment to the laboratory for analysis. The sampling procedure was repeated at each of the three ponds in order to obtain three separate frozen gas samples.

After preparation of the activated charcoal adsorption column in the laboratory according to ASTM D1354-60(8), the ends were sealed for transport to the field. Sampling in the field consisted of unsealing both ends of the adsorption column, connecting the column in line with the tube leading to the collection tent and the vacuum pump, and drawing a gas sample through the tube at the rate of 4 liters/min (0.1413 cfm) for one hour. Upon completion of the sampling, the ends were resealed on the adsorption column for return shipment to the laboratory for analysis. This procedure was repeated at each of the three ponds.

Laboratory Procedures

The air samples collected by the three separate methods--charcoal adsorption, low temperature condensation, and grab sampling with Teflon bags--were analyzed by gas-liquid chromatography and wet chemical methods.

Charcoal Samples--

The charcoal was removed from the sampling tubes, and placed in a 22mm x 300mm glass chromatography column with a porous glass bottom and Teflon stopcock. Each charcoal sample was extracted by adding 100 ml of carbon disulfide and allowing the sample to stand 20 minutes before draining. The carbon disulfide leachate was immediately analyzed by gas-liquid chromatography for mercaptans and sulfides.

Condensation Samples--

The sealed frozen condensate samples were removed from dry ice storage and placed in a 35°C water bath. Each sample was allowed to reach equilibrium temperature with the bath and then an air sample was removed with a 2.0 ml gas-tight GC syringe through a septum port on the sampling tube. The extracted air sample was immediately analyzed by gas-liquid chromatography for mercaptans and sulfides. The same procedure was repeated with the bath temperature maintained at 100°C. This allowed for a higher concentration of volatile components in the air space of the sampling tube.

Teflon Bag Samples--

Air samples were removed from the bags with a 2.0 ml gas-tight GC syringe and analyzed immediately by gas-liquid chromatography for methane, mercaptans, and sulfides. Hydrogen sulfide was determined by removing a known volume of air with a 100-ml luger-lok syringe and analyzing the air sample by the methylene blue photometric method.

SECTION 7

RESULTS

The results are grouped into three areas. The first describes the operation of the system components during the period of the study. The second summarizes and interprets the data collected on the vacuum filter and includes some mass balances. The third area presents the findings of the post-campaign odor study.

SYSTEM OPERATION

Personnel

During the campaign period of this study, the beet transport water system was operated by both factory-assigned personnel and by water system-assigned personnel. Overall responsibility for the system rested with the factory manager, although the Director of Technical Services, who also provided project liaison, provided technical assistance in the operation of the system. The rock catcher, beet washer, screens, grit chamber, flume water pumps, pH control equipment, and ancillary equipment related to beet handling were operated and maintained by factory-assigned personnel.

The clarifier, the Mud House, and the two lagoons were operated by special personnel under the direction of the water system supervisor. There were eleven people directly involved in the operation and maintenance of this part of the system; the supervisor, his assistant, six operators, and three helpers. The workday was divided into three 8-hour shifts that were rotated every two weeks to allow the operators and helpers to work different hours. (The operators and helpers are employed seasonally at MINN-DAK and most are farmers in the area.) The supervisor and his assistant, unless required by emergency situations or substituting for absent personnel, worked only during the first shift. The main duties of these two permanent MINN-DAK employees consisted of routine maintenance and repairs on the equipment. Factory maintenance personnel were also available for emergencies or for complicated equipment repairs.

Flume

The operation of the transport water system was predicated on the maintenance of a pH around 10. Low pH in the transport water resulted in foaming in the clarifier and foaming caused malfunctioning of the filtrate meter. The formation of bacterial slimes that tended to depress the pH also affected the filtration process by blinding the filter cloth. Maintenance of pH at the proper level was accomplished by dumping lime rock in the flume with a payloader. This was complemented by the addition of milk of lime when available. A more precise method for pH control of the flume water is one of the areas that needs attention.

Whenever the pH dipped below the desired level of 10, the operators requested the factory manager to add more lime. MINN-DAK's chief chemist indicated that they had experienced problems in maintaining the desired pH level during the 1976-77 campaign and that they were considering the use of a biocide in the future to retard bacterial action.

Clarifier

During this study, the clarifier was operated by a single operator each shift and sludge was pumped out continuously. At hourly intervals, the operator recorded the pump's motor load which was normally kept between 30 and 36 percent of capacity. He also visually monitored the level of the sludge surface and measured the settleable solids in the effluent with an Imhoff cone. The operator controlled the volume of the underflow pumped out of the clarifier by adjusting the setting on the pump. The underflow pumpage rate was not meter-controlled, but was noted as low, average, or high. Underflow density was controlled by changing the position of the suction snout. When the solids level in the clarifier rose too fast, the operator increased the pumping rate and raised the snout to increase the underflow removal rate.

The clarifier operator's duties included raking floating frozen solids out of the overflow trough. During periods of high foam and extremely low temperatures, however, factory maintenance crews were called upon to break out and remove frozen chunks from the clarifier. Operational problems were experienced with the pump and pipeline from the clarifier to the Mud House. The pump jammed on one occasion and the pipeline clogged several times due to sand and gravel, an indication of problems in the operation of the grit chamber (sand classifier) at the beet handling facility.

Mud House

At the Mud House, the hot lime mud from the factory and a portion of the clarifier underflow were brought together in the mixing tank where these two streams were blended by the action of a slow-moving coil. The level of the slurry was allowed to reach about mid-tank before the contents were allowed to flow to one of the two vacuum filters. The operators then tried to maintain this level by admitting all of the lime mud flow, and regulating the amount of clarifier underflow as necessary to maintain the tank level. This was done by operating the two gate valves on the clarifier underflow pipeline located near the mixing tank.

The gate valves were positioned at either end of a tee; the line to the mixing tank elbowed up while the bypass line to the lagoon elbowed down. The Mud House operators estimated the amount of underflow required and adjusted the valves accordingly. However, the operators did not know how much, if any, underflow was entering the tank because the compartment was closed on all sides and the steam created by the hot lime mud discharge made visual observation through small openings impossible. Also, the operators could not see the amount of underflow being bypassed to the lagoon without going outside the building.

The clarifier operator's main concern, as discussed earlier, was to maintain the mud level at a manageable depth. To accomplish that, he adjusted the percent motor load in the pump and the elevation of the suction snout, thereby randomly changing the flow rate and the solids content in the underflow. Since there was no telephone at the clarifier, and the distance between the clarifier and the Mud House was about 365 meters (1,200 ft), communications between these two installations took place only when a Mud House employee drove to the clarifier. Consequently, the Mud House operators were usually unaware of the conditions prevailing at the clarifier.

Almost all of the lime mud was taken into the mixing tank during the campaign. The only time lime mud was bypassed was during protracted filter shutdowns. On the other hand, most of the clarifier underflow was bypassed, for a variety of reasons. In general, adequate controls were lacking and underflow was often bypassed because less underflow resulted in fewer operational problems with the filters. Underflow was also bypassed whenever any of the following occurred: blinding of the filter cloth, washing of the filters, freezing of the cake in the pipeline due to extremely low temperatures, or breakdown of key equipment.

The vacuum filters were usually washed twice daily and sometimes three or four times, depending on the degree of cloth blinding which, in turn, depended upon the amount and quality of clarifier underflow admitted. Each washing operation lasted about one hour, but this usually resulted in a two-hour shutdown if the other filter was out of service. Shortly after the campaign started, one of the filters suffered a major breakdown when the blow-off unit was damaged, and it was out of service for more than a month, waiting for replacement parts.

Some of the more common mechanical problems experienced in the operation of the filters were agitator-bearing leaks and problems related to the operation of the cake blow-off system. Less frequent and less complex problems included plugging of the feed lines and loss of vacuum. Operational problems attributed to process flows were caused mainly by the variability in the characteristics of the clarifier underflow; volume, pH, solids content, and sand content. In a few cases, the lime mud caused problems but, overall, this flow was quite consistent, both in content and quantity. All of these problems are documented in the Mud House Log Summary in Appendix B.

The sludge pumps operated alternately during the campaign. These pumps were constantly under repair, mainly because of broken seals. At the end of the campaign these pumps are usually taken apart and given a complete overhaul consisting of repacking the pumps and resurfacing the cylinders.

Freezing of the filter cake in the sludge pipeline posed a particularly difficult problem in the operation of the system. The length of the pipeline, the low velocity of the cake, and the extremely cold North Dakota winter all contributed to this problem.

Lagoons

The sludge lagoons performed differently according to the characteristics of the materials conveyed to them. At the filter cake lagoon, the driest filter cake assumed a slight angle of repose--enough to permit free water to flow toward the lower elevations and eventually to the dead end of the drainage ditch. The wetter clarifier underflow sludge did not exhibit an angle of repose and the total mass flowed rather freely throughout the lagoon through an extensive network of canals carved in the mass by the fresh discharge and by water released from previously deposited sludge. At the far end of the lagoon, a culvert channelled the free water to the drainage ditch. This culvert eventually became submerged in the sludge and the water percolated through solids deposited in it. When the spring thaw arrived, water surfaced and covered 80 to 90 percent of the lagoon. Because of the dimensions of the lagoon, solar evaporation and slow seepage were the only means available to eliminate this water cover. The water cover kept this lagoon anaerobic, resulting in more objectionable odor conditions compared to the filter cake storage lagoon.

VACUUM FILTRATION

In the following interpretation of the analytical data, temperature, pH, dissolved COD, dissolved calcium, bulk density, percent solids, and viscosity are discussed for the entire study period. The results for total and dissolved solids, total COD, and total calcium are presented separately for the 22-hour and the 8-hour sampling groups. The data are presented as reported by the laboratory, without rounding.

Because pH values change with time due to bacterial action, pH data on the composited samples are not meaningful, and only instantaneous pH measurements are discussed here.

Temperature

Table 3 lists the average daily recorded temperatures of the clarifier underflow, the lime mud, the filtrate, and the ambient air in the Mud House. Daily high and low outdoor ambient temperatures are presented in Table A-4 in the Appendix as supplemental data.

The clarifier underflow average temperature ranged between 7°C and 18°C. The effect of the North Dakota weather on the clarifier underflow is reflected in the low temperature of the liquid, although it did not vary in proportion to the extreme fluctuations in the outside temperature.

The average temperature of the lime mud ranged from a low of 36°C to a high of 57°C, measured at the factory. It was then conveyed to the Mud House via an elevated, insulated pipeline, and it can be assumed that the lime mud was a few degrees cooler when it reached the Mud House.

The filtrate average temperature ranged from a low of 19°C to a high of 31°C. The contribution of lime mud to the filtrate is shown by the relatively high temperature of the filtrate. This contribution

TABLE 3. TEMPERATURE AND pH DATA

	Clarifier Underflow		Lime Mud	Filtrate		Mud House Ambient
DATE	Temp. °C	pH**	Temp. °C	Temp. °C	pH**	Temp. °C
11-9-76	7	--	--	24	--	16
11-10-76	8	--	--	25	--	16
11-12-76	12	--	--	21	--	16
11-14-76	12	7.0	--	26	10.2	16
11-15-76	11	7.3	--	25	6.8	17
11-16-76	10	8.2	--	24	8.8	15
11-17-76	9	10.2	--	26	7.1	16
11-18-76	13	9.2	--	26	7.0	18
11-19-76	15	8.7	--	26	6.8	16
11-21-76	9	7.2	--	30	8.9	17
11-22-76	10	8.1	--	26	8.5	16
11-23-76	14	7.5	52	29	7.2	13
11-24-76	13	8.5	50	24	6.9	16
11-25-76	12	10.0	42	21	8.3	17
11-26-76	10	8.8	43	23	6.8	16
11-28-76	18	7.7	45	30	6.1	22
11-29-76	16	7.7	45	29	7.6	16
11-30-76	14	7.6	41	28	7.7	14
12-1-76	13	8.9	51	28	6.6	13
12-2-76	12	7.8	57	27	6.8	14
12-3-76	11	7.7	56	28	6.8	17
12-5-76	14	7.9	54	30	6.8	15
12-6-76	14	8.7	54	27	7.9	14
12-7-76	11	7.8	52	27	6.9	14
12-8-76	12	7.9	53	27	6.5	14
12-9-76	12	7.8	52	28	6.5	15
12-10-76	11	7.0	53	25	6.9	14
12-12-76	15	6.3	54	31	6.5	16
12-13-76	12	6.1	54	29	6.9	18
12-14-76	14	6.4 (10)	54	28	6.8 (9.1)	14
12-15-76	17	6.8	54	30	6.6	15
12-16-76	17	6.6	53	30	6.3	15
12-17-76	15	6.5	53	29	6.4	15
12-19-76	12	5.0	53	30	6.5	13
12-20-76	13	4.8	51	25	7.0	22
12-21-76	13	4.8	47	27	6.2	22
12-22-76	15	5.0	50	27	6.7	21
12-23-76	14	5.0	49	28	5.9	21
12-24-76	13	6.0	50	31	6.5	17
12-26-76	13	5.9	50	28	6.8	17
12-28-76	11	4.8	47	25	9.6	11
12-29-76	13	4.7	46	27	7.2	13
12-30-76	13	6.6	43	29	6.6	13
12-31-76	14	6.6	42	30	6.9	12
1-2-77	13	6.1	45	30	6.4	17
1-3-77	10	5.5	43	27	6.4	15
1-4-77	10	5.3	47	26	5.7	16
1-5-77	10	5.7	46	26	6.5	16
1-6-77	8	--	38	22	--	13
1-7-77*	13	6.7	48	26	9.3	12
1-8-77*	11	--	--	25	--	13
1-9-77*	12	--	36	27	--	15
1-10-77*	13	5.6	--	19	7.4	11
1-11-77*	12	5.9	47	28	8.7	11
1-12-77*	14	5.5	--	28	8.4	17
1-13-77*	14	6.1	--	29	8.1	17

* Special monitoring period; 8-hour composites

** pH of composite samples reflecting changes due to biological action. Values in parentheses are instantaneous.

cannot be quantified without a knowledge of the specific heats of the liquids and slurries, heat losses in the Mud House, and other necessary data.

pH

The work plan did not include instantaneous pH measurements by the Mud House operators because of anticipated problems with pH meter operation and maintenance. More grab samples and/or provision for sample preservation during collection and before analysis would have provided useful data, but were not regarded as feasible within the scope of the study.

During a 4-hour period on December 14, 1976, five hourly grab samples were taken and the pH measured within 15 minutes of collection. The pH values ranged from 9.6 to 10.3 for the clarifier underflow and from 8.8 to 9.4 for the filtrate. These values indicate a decrease of two to four pH units due to storage of the samples during collection and before analysis. The instantaneous pH measurements are presented in Table A-3 of the Appendix.

Solids

Table 4 presents data on the total and volatile solids contents of the clarifier underflow, lime mud, filtrate, and filter cake. The total and volatile solids data for the lime mud and filter cake have been corrected for the bulk densities.

The clarifier underflow total solids content ranged from a low of 27.8 g/l to a high of 207 g/l. The high and low concentrations appear to have occurred in groups of five or more days at a time. The 8-hour samples had a mean total solids content of 79 g/l. Wide variations in the data throughout the study period reflect the effect of the sludge withdrawal method, the rate being continually adjusted by the clarifier operator.

The volatile solids content of the clarifier underflow showed a low of 10.8 g/l and a high of 36.4 g/l. The mean volatile solids content of the 8-hour samples was 20 g/l. The volatile solids constituted 20 to 25 percent of the total solids in the clarifier underflow.

The total solids in the lime mud ranged from a low of 443 g/l to a high of 774 g/l. The mean concentration for the 8-hour samples was 680 g/l. The data appear to be evenly dispersed throughout the data collection period with both high and low values occurring toward the end of the campaign. Very few problems were encountered with variations in the lime mud flow due to relatively steady conditions in the factory where this material originated.

The volatile solids content of the lime mud exhibited a low of 56.1 g/l and a high of 110 g/l. The mean concentration for the 8-hour samples was 77 g/l. The data generally show higher values occurring in the first half of the period, and lower values during the last half of the period, but these differences are minor. The volatile solid fraction was about 12 percent of the total solids.

TABLE 4. TOTAL AND VOLATILE SOLIDS DATA

DATE	Clarifier Underflow Total g/l	Clarifier Underflow Vol. g/l	Lime Mud Total g/l	Lime Mud Vol. g/l	Filtrate Total g/l	Filtrate Vol. g/l	Filter Cake Total g/l	Filter Cake Vol. g/l
11-14-76	49.1	16	731	110	37.1	33.7	--	--
11-15-76	61.9	14.9	686	95	29.2	23.8	--	--
11-16-76	90.9	19.2	753	107	22.6	19.7	846	96.4
11-17-76	119	22	708	107	34.5	30.6	825	102
11-18-76	115	24.7	--	--	42.1	38.4	822	106
11-19-76	78.5	18.5	669	108	41.7	37.1	823	106
11-21-76	49.4	15.5	724	103	55.5	40.1	800	98.2
11-22-76	119	22.4	720	102	33.6	30.1	822	98.9
11-23-76	181	29.1	627	89.6	26.5	22.3	845	102
11-24-76	161	25.4	660	88.3	24.8	18.9	804	89.9
11-25-76	80.4	14.2	585	76	25.3	20.5	822	93.2
11-26-76	110	19.1	631	86.9	42.6	27.8	830	95.3
11-28-76	191	32.9	597	92.6	53.2	42.5	896	111
11-29-76	135	29.1	647	88.4	111	54	852	103
11-30-76	113	23.5	605	91.2	105	48.2	854	108
12-1-76	168	32.4	682	86.5	32.6	25.2	839	96.8
12-2-76	156	29.1	765	109	39.4	34.2	859	105
12-3-76	207	35.3	716	99.6	37.5	32.5	902	107
12-5-76	78.6	19.6	711	85	37.7	31.9	849	89.3
12-6-76	73.5	18.6	705	96.6	46.6	38	797	92.9
12-7-76	96.3	22.3	742	92.8	36.3	30.1	892	93.4
12-8-76	70.7	18.8	745	92.6	34.2	26.5	936	95.1
12-9-76	53.2	15.8	710	101	38.4	30.6	855	95.3
12-10-76	27.8	10.8	729	100	62.3	31.5	839	92.4
12-12-76	85.6	23	681	81.2	33.1	27.3	838	88.6
12-13-76	35.3	13.5	689	81.8	24.1	15.6	849	93.4
12-14-76	33.5	12.6	769	78.2	38.8	26.6	873	87.1
12-15-76	162	36.4	704	78.5	22.4	17.3	818	83.1
12-16-76	143	30	695	85.7	29.2	24.7	799	95.1
12-17-76	119	23.4	703	81.4	27.2	23.0	805	81.8
12-19-76	28.6	11.7	703	79.6	28.9	22.2	870	87
12-20-76	53.2	16.6	664	86.7	22.9	19.4	824	91
12-21-76	155	32.2	607	73.1	29.5	26.6	820	84.5
12-22-76	175	33.2	677	74.9	24.1	20.5	854	89
12-23-76	74.7	19.6	672	85.5	29.4	26.2	860	87.8
12-24-76	97.9	23.1	648	86	38.4	32.9	869	90.4
12-26-76	97	27.2	688	93	40.9	33.5	856	96.5
12-27-76	108	23.7	680	82.0	30.6	24.5	839	86.7
12-28-76	64.9	18.1	705	76.2	38.6	23.7	919	85.6
12-29-76	95.3	27.2	702	82.2	28.8	21.0	898	93.5
12-30-76	84.6	24.7	443	56.1	34.4	30.8	854	83.0
1-2-77	110	24.4	576	65.7	19.5	16.1	841	84
1-3-77	112	28.8	610	83.5	29.9	26.9	814	95.2
1-4-77	68.5	17.9	651	85.7	29.3	26.3	855	96.1
1-5-77	84.9	22.2	603	80	26.9	24	792	88
1-7-77*	32.8	12.8	664	76.3	33.3	30	784	89.7
1-10-77*	74.7	19.7	613	64.4	21.1	18.2	881	76.4
1-11-77*	80.6	19.4	630	65.4	29.1	25.8	879	83.7
1-12-77*	77.9	19.7	730	83.7	33.5	30	879	89.7
1-13-77*	127	25.8	774	96	31.3	27.8	847	97.1

* Special monitoring period; 8-hour composites

The total solids content of the filtrate ranged from a low of 19.5 g/l to a high of 111 g/l. The mean concentration for the 8-hour samples was 30 g/l. With the exception of two very high values occurring on consecutive days, the data comprise a relatively narrow range of values. On November 29 and 30, 1976, problems were experienced with the clarifier pump and the underflow pipeline. It is suspected that the dilute clarifier underflow admitted to the mixing tank during this period caused a dirty filtrate because the low-solids slurry could not be efficiently filtered.

The volatile solids content of the filtrate exhibited a low value of 15.6 g/l and a high of 54 g/l. The mean concentration was 26 g/l for the 8-hour samples. The data show a relatively narrow range of values. The volatile fraction of the filtrate constituted 75 to 90 percent of the total solids.

The total solids content of the filter cake exhibited a low value of 784 g/l and a high value of 936 g/l. The mean value for the 8-hour samples was 850 g/l. The data are generally consistent, indicative of uniform performance by the filters.

The volatile solids content of the filter cake exhibited a low value of 76.4 g/l and a high value of 111 g/l. The 8-hour samples had a mean volatile solids content of 87 g/l. The data show the same even distribution and narrow range of values as the total solids content. The volatile fraction constituted about 10 percent of the total solids in the filter cake.

Chemical Oxygen Demand (COD)

Table 5 lists the daily total COD values of the clarifier underflow, lime mud, filtrate, and filter cake. Dissolved COD values, also given in Table 5, were measured weekly.

The concentration of total COD in the clarifier underflow ranged from 13,500 mg/l to 60,300 mg/l. The mean value was 30,000 mg/l for the 8-hour samples. The expected increase in total COD due to beet deterioration was not readily evident in the data distribution, since high and low values were measured throughout the study.

The concentration of dissolved COD in the clarifier underflow exhibited a low of 7,450 mg/l and a high of 24,900 mg/l, with a mean of 16,000 mg/l. The general trend is toward higher COD values with the progress of the campaign. The mean total COD of the samples also analyzed for dissolved COD was 37,000 mg/l.

The total COD of the lime mud ranged from 26,700 mg/l to 127,000 mg/l. The mean was 51,000 mg/l for the 8-hour samples. The data show high values of total COD in the lime mud during the first half of the study and lower values for the second half. Changes in the carbonation process at the factory are believed to be responsible for this change.

The dissolved COD of the lime mud showed a low concentration of 22,100 mg/l and a high of 57,500 mg/l, with a mean concentration of 29,000 mg/l.

TABLE 5. TOTAL AND DISSOLVED COD DATA

DATE	Clarifier Underflow Total mg/l	Clarifier Underflow Dis. mg/l	Lime Mud Total mg/l	Lime Mud Dis. mg/l	Filtrate Total mg/l	Filtrate Dis. mg/l	Filter Cake Total mg/l	Filter Cake Dis. mg/l
11-14-76	17,800	--	111,000	--	35,900	--	90,200	--
11-15-76	21,500	--	114,000	--	26,300	--	149,000	--
11-16-76	26,800	--	85,300	--	21,000	--	75,000	--
11-17-76	42,300	7,450	80,700	22,100	32,700	33,100	91,000	24,800
11-18-76	33,200	--	54,100	--	40,600	--	73,100	--
11-19-76	28,900	--	69,200	--	--	--	93,000	--
11-21-76	13,500	--	44,300	--	--	--	54,500	--
11-22-76	27,500	14,100	114,000	57,500	81,500	32,500	121,000	20,900
11-23-76	46,500	--	127,000	--	53,700	--	148,000	--
11-24-76	25,400	--	78,200	--	91,600	--	100,000	--
11-25-76	23,200	--	58,700	--	17,600	--	87,300	--
11-26-76	30,000	--	58,800	--	37,500	--	89,100	--
11-28-76	49,400	--	97,200	--	56,000	--	116,000	--
11-29-76	44,400	9,320	83,800	53,000	--	--	126,000	43,700
11-30-76	60,300	--	95,300	--	51,600	--	114,000	--
12-1-76	46,400	--	63,400	--	25,000	--	92,000	--
12-2-76	44,300	--	117,500	--	45,900	--	119,000	--
12-3-76	47,800	--	103,000	--	46,400	--	108,000	--
12-5-76	36,200	--	95,200	--	43,500	--	116,500	--
12-6-76	33,500	13,400	85,000	51,300	48,300	44,400	121,000	44,500
12-7-76	35,700	--	95,500	--	42,900	--	102,000	--
12-8-76	30,500	--	95,400	--	37,600	--	81,300	--
12-9-76	26,700	--	109,000	--	41,000	--	108,000	--
12-10-76	25,500	--	112,000	--	110,000	--	94,600	--
12-13-76	31,000	18,500	75,100	33,100	30,400	25,500	73,100	22,100
12-14-76	26,400	--	83,500	--	39,100	--	88,000	--
12-15-76	51,400	--	66,300	--	35,250	--	82,300	--
12-16-76	42,800	--	79,700	--	38,100	--	82,500	--
12-17-76	38,400	--	51,200	--	35,700	--	73,700	--
12-19-76	16,600	--	66,900	--	36,800	--	82,600	--
12-20-76	32,800	24,900	69,750	42,200	36,300	28,200	64,300	24,500
12-21-76	48,300	--	67,600	--	41,000	--	60,500	--
12-22-76	45,800	--	65,600	--	37,300	--	67,000	--
12-23-76	34,600	--	60,700	--	29,900	--	62,200	--
12-24-76	38,600	--	71,900	--	44,400	--	85,600	--
12-26-76	43,400	--	73,600	--	46,200	--	98,300	--
12-28-76	34,000	--	53,900	--	38,300	--	57,600	--
12-29-76	46,400	--	52,700	--	35,700	--	64,000	--
12-30-76	42,700	--	40,200	--	36,100	--	69,800	--
12-31-76	43,500	--	49,300	--	51,900	--	81,800	--
1-2-77	44,900	--	48,400	--	21,600	--	74,600	--
1-3-77	46,600	18,500	59,300	25,900	32,200	35,200	74,300	21,800
1-4-77	29,900	--	26,700	--	46,100	--	59,500	--
1-5-77	45,800	--	42,400	--	29,800	--	66,500	--
1-7-77*	15,600	--	48,200	--	32,800	--	64,000	--
1-10-77*	29,200	--	43,000	--	26,800	--	66,700	--
1-11-77*	40,800	24,600	43,000	25,700	30,800	32,100	52,150	16,900
1-12-77*	28,800	--	58,300	--	36,900	--	65,800	--
1-13-77*	37,100	--	61,500	--	34,700	--	63,300	--

* Special monitoring period; 8-hour composites

The dissolved COD values are evenly distributed throughout the study period. The mean total COD of the samples from which the dissolved values were obtained was 76,000 mg/l.

The total COD of the filtrate exhibited a low concentration of 17,600 mg/l and a high concentration of 110,000 mg/l. The mean concentration was 32,000 mg/l for the 8-hour samples. The distribution of values appears uniform with respect to time. As with the lime mud, higher values of total COD in the filtrate occurred in the first half of the study period and lower values in the second half.

The dissolved COD of the filtrate exhibited a low concentration of 25,500 mg/l and a high concentration of 44,400 mg/l, with a mean concentration of 33,000 mg/l. The mean total COD of the samples from which the dissolved values were determined was 42,000 mg/l. It may be noted that in the case of low total COD values (11-17-76, 1-3-77, and 1-11-77) the corresponding dissolved COD values exceeded the total values. This is attributed to analytical and sampling errors.

The total COD of the filter cake varied from a low of 52,200 mg/l to a high of 149,000 mg/l. The mean value was 62,000 mg/l for the 8-hour samples. The distribution of values shows that, as with the lime mud and filtrate COD values, higher concentrations of total COD prevailed during the first half of the data collection period and lower concentrations during the last half.

The dissolved COD of the filter cake had a low concentration of 16,900 mg/l, a high concentration of 44,500 mg/l, and a mean concentration of 27,000 mg/l. The total COD of the samples analyzed for dissolved COD had a mean value of 90,000 mg/l. The data show generally higher dissolved COD values during the first half of the study period and lower values toward the end, with the lowest dissolved COD value corresponding to the lowest total COD value.

Calcium

Measurements of calcium, as Ca, are presented in Table 6, and include both total and dissolved concentrations of calcium in the clarifier underflow, lime mud, filtrate, and filter cake.

The total calcium concentration of the clarifier underflow had a low value of 814 mg/l and a high value of 7,310 mg/l. The means were 3,200 mg/l for the 22-hour samples and 1,400 mg/l for the 8-hour samples. The only pattern discernible is that groupings of three to five consecutive measurements are in the same range of concentration. This is attributed to batch liming of the flume to control pH.

The dissolved calcium concentration of the clarifier underflow exhibited a low of 536 mg/l, a high of 2,000 mg/l, and a mean value of 1,000 mg/l. The high dissolved calcium concentration corresponded to the high total calcium value; the dissolved fraction constituted about one third of the total calcium.

TABLE 6. TOTAL AND DISSOLVED CALCIUM DATA

DATE	Clarifier Underflow Total mg/l	Clarifier Underflow Dis. mg/l	Lime Mud Total mg/l	Lime Mud Dis. mg/l	Filtrate Total mg/l	Filtrate Dis. mg/l	Filter Cake Total mg/l	Filter Cake Dis. mg/l
11-16-76	4,160	--	199,000	--	657	--	209,000	--
11-17-76	4,570	--	222,000	--	942	--	227,000	--
11-18-76	4,141	728	104,000	1,860	2,120	871	267,000	2,180
11-19-76	3,380	664	205,000	1,760	1,535	950	256,000	2,430
11-21-76	1,700	657	228,000	1,210	2,690	657	261,000	3,050
11-22-76	3,930	851	237,000	2,670	885	942	220,000	1,590
11-23-76	5,900	928	197,000	785	1,357	650	224,000	1,960
11-24-76	4,080	785	201,000	952	1,590	862	213,000	1,710
11-25-76	3,680	593	192,000	1,240	1,640	600	230,000	2,330
11-26-76	4,170	652	215,000	1,110	4,970	1,280	227,000	1,570
11-29-76	4,710	961	185,000	1,330	5,310	1,120	276,000	--
11-30-76	3,510	1,070	208,000	1,490	--	1,640	289,000	2,780
12-1-76	4,905	1,365	241,000	1,050	3,940	1,080	260,000	1,330
12-2-76	5,160	1,180	252,000	1,000	1,370	1,020	251,000	2,860
12-3-76	6,650	843	234,000	807	1,435	814	257,000	2,800
12-5-76	3,870	1,440	224,000	864	1,810	1,000	270,000	3,105
12-6-76	3,850	1,365	266,000	700	2,910	1,100	264,000	--
12-7-76	3,710	1,390	224,000	1,980	1,480	1,090	293,000	2,400
12-8-76	3,260	1,340	247,000	835	2,330	1,190	280,000	1,980
12-9-76	3,010	1,210	226,000	1,060	2,105	1,340	280,000	1,840
12-10-76	1,880	1,310	219,000	1,060	--	1,660	258,000	2,335
12-12-76	3,930	1,610	206,000	571	1,470	1,290	245,000	2,830
12-13-76	1,640	1,240	215,000	835	2,860	1,180	286,000	2,200
12-14-76	1,910	1,290	242,500	1,700	4,090	1,360	279,000	2,330
12-15-76	7,310	2,000	231,000	543	1,510	1,555	239,000	1,890
12-16-76	6,170	1,650	229,000	578	1,310	1,190	219,000	2,250
12-17-76	4,700	1,640	209,000	478	1,190	1,190	232,000	1,950
12-19-76	814	807	231,000	571	2,010	1,010	288,000	1,730
12-20-76	928	600	219,000	1,185	885	835	224,000	2,000
12-21-76	1,900	921	199,000	571	757	740	237,000	2,580
12-22-76	1,700	785	227,000	571	650	607	223,000	928
12-23-76	1,240	911	224,000	743	771	764	271,000	2,370
12-24-76	2,070	1,710	218,000	628	1,480	1,120	259,000	2,240
12-26-76	2,460	1,580	226,500	700	2,330	1,210	247,000	1,750
12-27-76	2,080	1,240	229,000	650	1,940	878	247,000	2,870
12-28-76	985	635	227,000	735	2,520	764	300,000	1,035
12-29-76	1,060	536	211,000	614	2,570	743	282,000	1,510
12-30-76	2,035	1,185	151,000	1,060	907	843	276,000	2,000
12-31-76	2,080	1,120	163,000	618	971	878	250,000	1,090
1-2-77	2,030	1,010	198,000	528	850	850	272,000	904
1-3-77	1,790	871	201,000	871	821	821	255,000	2,145
1-4-77	1,210	643	208,000	1,520	778	728	247,000	3,220
1-5-77	1,300	578	194.000	785	800	728	267.000	2.230
1-7-77*	1,080	757	223,000	468	843	564	263,000	571
1-10-77*	1,460	721	207,000	514	750	600	276,000	657
1-11-77*	1,410	585	207,000	543	935	621	296,000	634
1-12-77*	1,260	600	234,000	528	764	628	260,000	743
1-13-77*	1,890	797	246,000	628	885	835	242,000	1,030

* Special monitoring period; 8-hour composites

The lime mud had a low total calcium content of 104,000 mg/l and a high total calcium content of 266,000 mg/l. The mean values were 210,000 mg/l for the 22-hour samples and 220,000 mg/l for the 8-hour samples. The values were evenly distributed throughout the study period.

The dissolved calcium content of the lime mud ranged from a low concentration of 468 mg/l to a high of 2,670 mg/l, with a mean value of 1,000 mg/l. The concentration distribution begins with higher values and then diminishes as the campaign progressed, interspersed with occasional high values. The dissolved fraction was generally less than one percent of the total calcium.

The filtrate exhibited a low total calcium concentration of 650 mg/l and a high concentration of 5,310 mg/l. The mean values were 1,800 mg/l for the 22-hour samples and 840 mg/l for the 8-hour samples. The spread of values was very wide, with the lowest value being only about 12 percent of the highest value.

The dissolved calcium content of the filtrate exhibited a low value of 564 mg/l, a high value of 1,660 mg/l, and a mean value of 1,000 mg/l. For total calcium concentrations up to about 1,200 mg/l, the dissolved calcium ranged from 70 percent to 100 percent of the total. On the average, the dissolved calcium constituted about 55 percent of the total calcium present.

The filter cake had a total calcium concentration ranging from a low value of 209,000 mg/l to a high of 300,000 mg/l. The mean concentrations were 260,000 mg/l for the 22-hour samples and 270,000 mg/l for the 8-hour samples. The values were evenly distributed and consistent with the distribution of the waste lime calcium concentrations.

The dissolved calcium of the filter cake had a low value of 571 mg/l, a high value of 3,220 mg/l, and a mean value of 2,100 mg/l. With the exception of the substantially lower values measured on the 8-hour samples, the concentration distribution appears uniform throughout the study period.

Bulk Density and Percent Solids

Table 7 presents the bulk density and percent solids data for the clarifier underflow, lime mud, filter cake, and cake storage samples. The cake storage data are presented for comparison with the filter cake data. The cake storage samples are essentially the same as the filter cake samples except that water was added to facilitate pumping of the cake to the storage lagoon. The filtrate, because it is essentially water with a relatively low solids content, was not analyzed for bulk density. The bulk density of samples was determined gravimetrically. The percent solids data show the weight of dry solids per 100 grams of wet sample.

The bulk density of the clarifier underflow ranged from 0.99 to 1.10 g/ml, with a mean value of 1.04 g/ml for both groups of samples. The variation in bulk density is related to the amount and type of solids present in the sample and the distribution of values appears to be relatively even throughout the study, with a few exceptions. About 80 percent of the values

TABLE 7. BULK DENSITY AND PERCENT SOLIDS DATA **

DATE	Clarifier Underflow g/ml	Clarifier Underflow %	Lime Mud g/ml	Lime Mud %	Filter Cake g/ml	Filter Cake %	Cake Storage g/ml	Cake Storage %
11-14-76	1.04	4.7	1.41	51.8	--	--	1.51	56.0
11-15-76	1.02	6.1	1.42	48.3	1.49	--	1.46	55.2
11-16-76	1.05	8.7	1.48	50.9	1.50	56.4	1.42	55.8
11-17-76	1.03	11.6	1.46	48.5	1.48	55.7	1.56	56.1
11-18-76	1.03	11.2	1.39	--	1.47	55.9	1.45	55.4
11-19-76	1.05	7.5	1.39	48.1	1.47	56.0	1.47	54.9
11-21-76	1.03	4.8	1.41	51.3	1.48	54.1	1.46	56.0
11-22-76	1.01	11.8	1.41	51.1	1.48	55.5	1.45	53.9
11-23-76	1.01	17.9	1.37	45.8	1.49	56.7	1.45	53.9
11-24-76	1.04	15.5	1.39	47.5	1.47	54.7	1.44	53.8
11-25-76	1.01	8.0	1.33	44.0	1.49	55.2	1.47	54.0
11-26-76	1.04	10.6	1.39	45.4	1.49	55.7	1.45	53.2
11-28-76	1.03	18.5	1.38	43.3	1.52	58.9	1.48	54.7
11-29-76	1.03	13.1	1.37	47.2	1.49	57.2	1.46	54.7
11-30-76	1.04	10.9	1.36	44.5	1.50	56.9	1.44	52.4
12-1-76	1.00	16.8	1.40	48.7	1.50	55.9	1.47	54.1
12-2-76	0.99	15.8	1.45	52.8	1.51	56.9	1.48	54.8
12-3-76	1.03	20.1	1.43	50.1	1.52	59.3	1.51	56.2
12-5-76	1.02	7.7	1.41	50.4	1.52	55.9	1.48	58.2
12-6-76	1.04	7.1	1.42	49.6	1.48	53.9	1.52	56.1
12-7-76	1.04	9.3	1.44	51.5	1.54	57.9	1.51	57.0
12-8-76	1.04	6.8	1.44	51.7	1.53	61.2	1.52	56.6
12-9-76	1.02	5.2	1.42	50.0	1.51	56.6	1.50	55.6
12-10-76	1.02	2.7	1.43	51.0	1.49	56.3	1.48	52.7
12-12-76	1.05	8.2	1.40	48.6	1.50	55.9	1.49	54.9
12-13-76	1.03	3.4	1.40	49.2	1.51	56.2	1.49	56.6
12-14-76	1.01	3.3	1.44	53.4	1.54	56.7	1.50	53.1
12-15-76	1.03	15.7	1.43	49.2	1.50	54.5	1.48	53.8
12-16-76	1.07	13.4	1.42	48.9	1.48	54.0	1.48	54.3
12-17-76	1.07	11.1	1.42	49.5	1.49	54.0	1.47	52.9
12-19-76	1.02	2.8	1.41	49.9	1.53	56.9	1.51	55.9
12-20-76	1.03	5.2	1.39	47.8	1.49	55.3	1.47	53.7
12-21-76	1.09	14.2	1.37	44.3	1.49	55.0	1.47	52.7
12-22-76	1.10	15.9	1.40	48.4	1.53	55.8	1.49	53.8
12-23-76	1.05	7.1	1.40	48.0	1.53	56.2	1.49	54.2
12-24-76	1.06	9.2	1.38	47.0	1.54	56.4	1.48	53.7
12-26-76	1.06	9.2	1.41	48.8	1.52	56.3	1.51	54.6
12-27-76	1.07	10.1	1.41	48.2	1.52	55.2	1.49	55.1
12-28-76	1.04	6.2	1.43	49.3	1.55	59.3	1.51	55.2
12-29-76	1.05	9.1	1.42	49.4	1.54	58.3	1.49	55.8
12-30-76	1.05	8.1	1.26	35.2	1.52	56.2	1.51	55.5
12-31-76	1.04	9.5	1.30	38.4	1.49	54.2	1.47	51.4
1-2-77	1.06	10.4	1.35	42.7	1.51	55.7	1.50	53.8
1-3-77	1.06	10.6	1.36	44.9	1.48	55.0	1.46	52.0
1-4-77	1.04	6.6	1.39	46.8	1.50	57.0	1.48	53.3
1-5-77	1.03	8.2	1.36	44.3	1.48	53.5	1.47	52.4
1-7-77*	1.02	3.2	1.40	47.4	1.48	53.0	1.48	53.6
1-10-77*	1.03	7.3	1.37	44.7	1.54	57.2	1.53	56.8
1-11-77*	1.04	7.8	1.38	45.7	1.54	57.1	1.50	54.9
1-12-77*	1.05	7.4	1.44	50.7	1.53	57.5	1.50	55.8
1-13-77*	1.06	12.0	1.46	53.0	1.52	55.7	1.49	54.8

* Special monitoring period; 8-hour composites
** Percent solids by weight

ranged between 1.02 and 1.06 g/ml.

The percent solids of the clarifier underflow ranged from a low value of 2.7 percent to a high of 20.1 percent with a mean value of 9.6 percent. The data generally show higher values during the initial part of the data collection period and lower values toward the end of the campaign.

The bulk density of the lime mud ranged from a low value of 1.26 to a high of 1.48 g/ml, with a mean value of 1.4 g/ml. The bulk density of the lime mud varied within a narrow range of values throughout the study period.

The percent solids of the lime mud had a low value of 35.2 percent, a high value of 53.4 percent, and a mean value of 48 percent. The percent solids data of the lime mud samples agree well with the bulk density data, showing only slight variation with respect to time.

The bulk density of the filter cake had a low value of 1.47 g/ml, a high value of 1.55 g/ml, and a mean value of 1.50 g/ml. The filter cake bulk density varied little throughout the study period; all values were within 5 percent of one another.

The percent solids of the filter cake had a low value of 53 percent, a high value of 61.2 percent, and a mean value of 56 percent. All of the values occurred within a narrow range, although not as narrow as the bulk density values.

The bulk density of the cake storage samples ranged from a low value of 1.42 to a high of 1.52 g/ml, with a mean value of 1.48 g/ml. The data are evenly distributed with respect to time. The added water in the cake storage samples reduced the solids content by about 3 percent compared to the filter cake samples.

Viscosity

A limited number of viscosity measurements were made by MINN-DAK on clarifier underflow, lime mud, filter cake, and filter cake storage samples. The data are presented in Table A-3 of the Appendix, with the cake storage samples omitted because of their limited value.

It was concluded from the viscosity measurements that the samples tested were non-Newtonian fluids exhibiting changes in viscosity with respect to duration and rate of shear application. These changes were attributed to non-symmetrical composition and to cohesiveness within the slurries. Non-symmetrical composition of the samples refers to the presence of large molecules, colloids, and suspended solids.

The clarifier underflow and the lime mud samples, for which the viscosity measurements have meaning, had average viscosities of 40 and 1,200 centipoises, respectively. The filter cake viscosity values averaged 27,000 centipoises. The viscosity measurements were made at temperatures of from 22°C to 26°C.

The bulk density and percent solids data, with the exception of the clarifier underflow, were quite consistent throughout the data collection period. They also show the negligible contribution of solids from the clarifier underflow to the filter cake solids.

Typical Flow Rates and Mass Balances

Figure 6 depicts a typical flow balance for the Mud House operation. The balance was constructed using actual operating data, measured flows, estimated flows based on assumed values from observed operations, and adjustments of the actual data.

In the balancing procedure, the filtrate flow rate was given the highest reliability. Following, in order of decreasing reliability, were the calculated filter cake and the lime mud flow rates. While the total underflow out of the clarifier could be determined with a high degree of confidence, its distribution between the mixing tank and the bypass flows could be determined only by balancing the filtration process input and output flows. As noted above, the methods employed by the operators to control the amount of clarifier underflow admitted into the mixing tank did not give reliable estimates of flow rates. For this reason, the flow rate of the clarifier underflow into the mixing tank was made to fit the balancing equation.

The filtrate flow rate was obtained from actual data recorded on the log sheets. However, faulty data due to liquid aeration and other operational problems produced wide fluctuations in the instantaneous flow meter readings. A careful evaluation of the data was therefore required to screen out spurious results and to select those operating periods that were judged to have produced reliable data. The filtrate flow rate for each day for which reliable data were obtained was calculated and entered, including the operating hours, in the Mud House log summary. These flow data are presented in Table A-1 of the Appendix. An actual average flow rate of 166 cu m/day (30 gpm) was obtained.

The sludge pump stroke counters installed to measure the rate of filter cake production did not yield useful results. When the operating logs were reviewed, it was determined that each operator exercised different criteria to estimate the effective stroke length of the pump cylinder. Some operators measured and recorded the distance to be subtracted from the full stroke while others estimated and recorded the effective stroke. Consequently, the stroke counter data were discarded because they were judged to be inconsistent.

The filter cake production rate was calculated using the filter dimensions, rotational speed, and observed typical filter cake thickness as follows:

Filtering area per revolution: 63 sq m
Rotational speed: 1 revolution/2.5 min
Cake thickness: 1.05 cm
Production rate = (63 sq m/rev)(0.0105 m)(1 rev/2.5 min)(1440 min/day)
= 382 cu m/day (70 gpm)

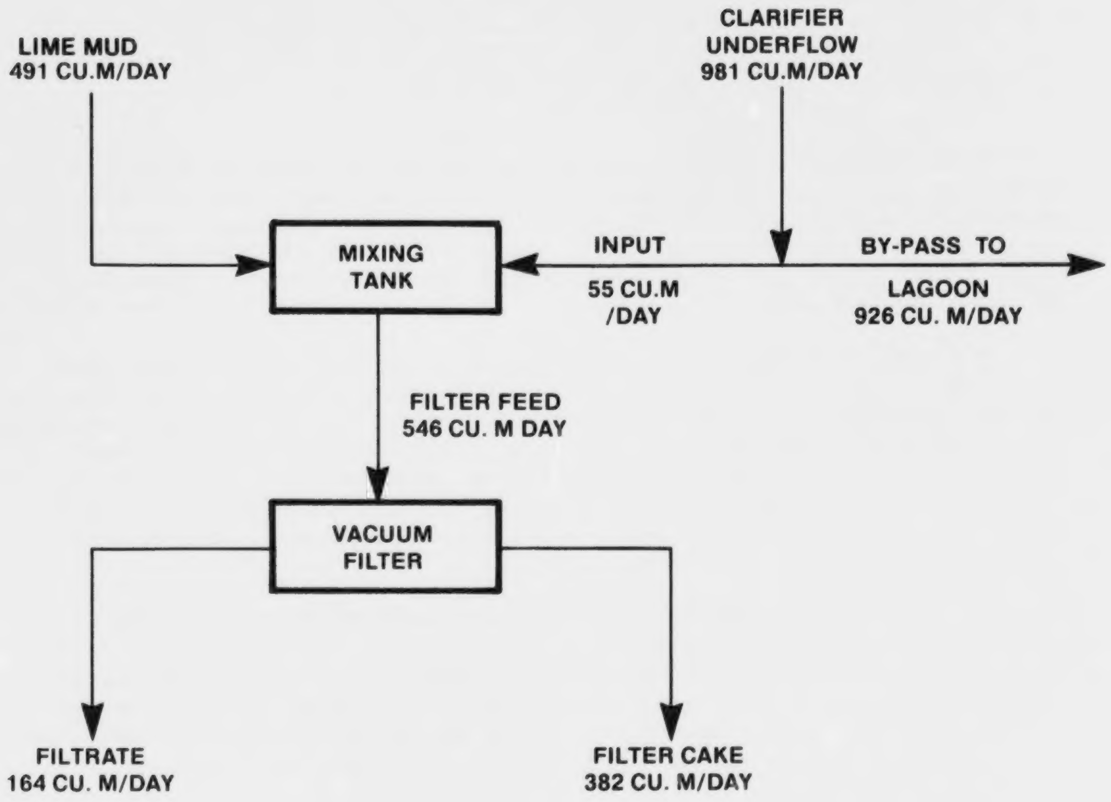

LIME MUD
491 CU.M/DAY
CLARIFIER
UNDERFLOW
981 CU.M/DAY
MIXING
TANK
INPUT
55 CU.M
/DAY
BY-PASS TO
LAGOON
926 CU. M/DAY
FILTER FEED
546 CU. M DAY
VACUUM
FILTER
FILTRATE
164 CU. M/DAY
FILTER CAKE
382 CU. M/DAY

Figure 6. Typical process flows.

The thickness of the filter cake varied between 0.6 cm and 1.6 cm (1/4 to 5/8 in). A variation of 0.15 cm (1/16 in) in the thickness of the cake produces a theoretical variation in the flow rate of about 55 cu m/day (10 gpm).

An attempt was made to calculate a theoretical rate of flow for lime mud using lime production and waste lime calcium concentration data for a six-day period as follows:

Lime production: 93,700 kg/day, as CaO
Waste lime calcium concentration: 220 g/l, as Ca
Calculated lime concentration: 308 kg/cu m, as CaO
Flow rate = (93,700 kg/day)/(308 kg/cu m)
= 304 cu m/day (56 gpm)

This theoretical value, however, was below the range of 327 to 600 cu m/day (60 to 110 gpm) observed during the lime mud and clarifier underflow measurement studies carried out near the end of the campaign. Based on total calcium, the bulk of which is accounted for by the lime mud and the filter cake, trial and error calculations fixed the lime mud flow rate at 491 cu m/day (90 gpm).

The data in Table A-2 of the Appendix, relating the clarifier pump discharge to percent motor load, were used to determine the total flow rate of the clarifier underflow. The estimated 34 percent motor load corresponds to a flow rate of 981 cu m/day (180 gpm). A clarifier underflow input of 55 cu m/day (10 gpm) to the filtration process was determined by balancing the flow equation with the remaining flow of 926 cu m/day (170 gpm) being by-passed to the lagoon. This split appears consistent with the observed operation of the control valves.

Tables 8 and 9 summarize the general operations and filtration process data, respectively, for a typical day's operation. The operations data in Table 8 are mean calculated values for production and analytical parameters measured throughout the study period. Table 9 contains adjusted mean values of analytical data for the samples collected during typical Mud House operation, that is, for the 22-hour samples collected through January 6, 1977. The values were adjusted slightly to attain mathematical balances; e.g., the mean total solids concentration of the clarifier underflow was changed from 102 g/l to 101 g/l. Omitted from this table are the dissolved COD and the dissolved calcium balances. In the case of the dissolved COD, it was judged that the number of analytical values was not sufficient to produce significant results. The relatively low concentrations of dissolved calcium, compared to the total calcium concentrations, did not contribute significantly to the balancing process.

The mass balances conclusively show the preponderance of the lime mud in the input to the vacuum filtration system. The lime mud to clarifier underflow ratios are: 8.9 for flow; 58.5 for total solids; 34.5 for volatile solids; 17.9 for total COD; and 506 for total calcium. The filtration process was effective in removing 98 percent of the total solids, 88 percent of the volatile solids, 83 percent of the total COD, and practically all of

TABLE 8. GENERAL DATA OF A TYPICAL DAY'S OPERATION

Beets processed: 3,500 metric tons/day

CaO produced: 91 metric tons/day

Ambient air temperature range: low -18°C; high -7°C

Mud House ambient air temperature: 15°C

Clarifier pump load setting: 34 percent

Clarifier underflow pumping rate: 981 cu m/day

Total solids out of the clarifier: 98 kkg/day

Dirt tare as percentage of beet weight: 3.3%

	pH	Temp. °C	Solids %	Bulk Density abs.	Viscosity cp
Clarifier Underflow	9.6 - 10.3	12	9.6	1.04	40
Lime Mud	--	49	47.9	1.40	1,210
Filtrate	8.8 - 9.4	27	--	--	--
Filter Cake	--	--	56.1	1.50	27,000

TABLE 9. FILTRATION PROCESS DATA - TYPICAL DAY'S OPERATION

		Total Solids		Volatile Solids		Total COD		Total Ca	
	Flow cu m/day	Conc. g/l	Mass kkg/day	Conc. g/l	Mass kkg/day	Conc. g/l	Mass kkg/day	Conc. g/l	Mass kkg/day
Clarifier Underflow	55	101	6.0	22.0	1.2	38.0	2.1	3.0	0.2
Lime Mud	491	667	327	84.3	41.4	76.4	37.5	206	101.1
Total Input	546	--	333	--	42.6	--	39.6	--	101.3
Filtrate	164	37.7	6	33.0	5.4	40.7	6.7	1.7	0.3
Filter Cake	382	856	327	98.9	37.8	86.3	33.0	265	101.1
Total Output	546	--	333	--	43.2	--	39.7	--	101.4

the total calcium.

Special Monitoring Period

During the last five days of the campaign, a special program was instituted to monitor closely the operation of the Mud House during exemplary operating conditions. This program took place from January 7, 1977, to the end of the data-collecting period, January 13, 1977. The daily program included collection of samples and close observation of the operations during the first shift. The data are presented above, with the mean of the 5-day data points identified as the 8-hour samples.

Table 10 shows a mass balance of the vacuum filtration process for this special 5-day operating period. To construct the mass balance, the flows had to be adjusted to correspond to the altered analytical results. The assumed flow rate of the lime mud was kept at its previous value. Trial and error calculations were made using the mean concentrations for the period until a close balance was achieved and the flow rates for the other three streams were fixed. The clarifier underflow doubled to 109 cu m/day, the filtrate increased from 164 cu m/day to 210 cu m/day, and the filter cake was essentially unchanged, from 382 cu m/day to 390 cu m/day.

After the flow rates were fixed, the concentrations were adjusted to effect a mathematical mass balance, e.g., the total solids concentration of the clarifier underflow changed from 8.6 to 8.5 g/l, while the total calcium concentration was unchanged.

The mass balance for this special monitoring period shows that the filtration process did not change significantly compared to the typical operation previously discussed and presented in Table 9. The values in Table 10 indicate that although higher clarifier underflow total solids, volatile solids, and total COD were processed, the increases were quite modest and were offset by the reduction in the removal of COD. Total calcium remained unchanged.

In summary, the dewatering system was not adequately separating the clarifier underflow solids from the transporting water because clarifier underflow was being bypassed. Under the best operating conditions, the 8.5 kkg/day of total solids in the clarifier underflow admitted into the filtration process constitute only nine percent of the 99 kkg/day of total solids pumped from the clarifier.

ODOR EVALUATION

The results of the odor panel tests are listed in Table 11 and displayed in Figure 7. The quantities of gas produced by each of the ponds are listed in Table 12 and graphically displayed in Figure 8.

Odor concentration and gas production for each of the ponds were correlated with several other measured parameters; namely, surface water temperature, COD, pH, and TDS (Figures 9 and 10). Often there was good positive correlation between certain parameters in one pond, but no correlation for

TABLE 10. FILTRATION PROCESS DATA - SPECIAL FIVE-DAY PERIOD OPERATION

	Flow cu m/day	Total Solids Conc. g/l	Total Solids Mass kkg/day	Volatile Solids Conc. g/l	Volatile Solids Mass kkg/day	Total COD Conc. g/l	Total COD Mass kkg/day	Total Ca Conc. g/l	Total Ca Mass kkg/day
Clarifier Underflow	109	78.0	8.5	19.3	2.1	32.1	3.5	1.7	0.2
Lime Mud	491	678	333	76.8	37.7	53.2	26.1	218	107
Total Input	600	--	341.5	--	39.8	--	29.6	--	107.2
Filtrate	210	29.5	6.2	26.7	5.6	31.0	6.5	0.9	0.2
Filter Cake	390	859	335	87.7	34.2	59.2	23.1	274	107
Total Output	600	--	341.2	--	39.8	--	29.6	--	107.2

TABLE 11. ODOR CONCENTRATION

Date	Odor Conc., ou/ft^3	Odor Type
	Mud Pond	
4-20-77	50	Acidic - musty
5-2-77	170	Stale river
5-13-77	960	Acidic - Stale river
5-26-77	5.5	Acidic - Stale river
6-20-77	600	H_2S - Stale river
7-12-77	9	Stale river
	Lime Pond	
4-20-77	50	Acidic - musty
5-2-77	70	Acidic - musty
5-13-77	1,600	Acidic - musty
5-26-77	38	Acidic - musty
6-20-77	12	H_2S - musty
7-12-77	14	Pig Pen
	Pond #2	
4-20-77	440	Pig tail
5-2-77	1,300	Pig tail - musty
5-13-77	47,000	H_2S
5-26-77	1,000	H_2S
6-20-77	270	H_2S
7-12-77	4.5	Musty

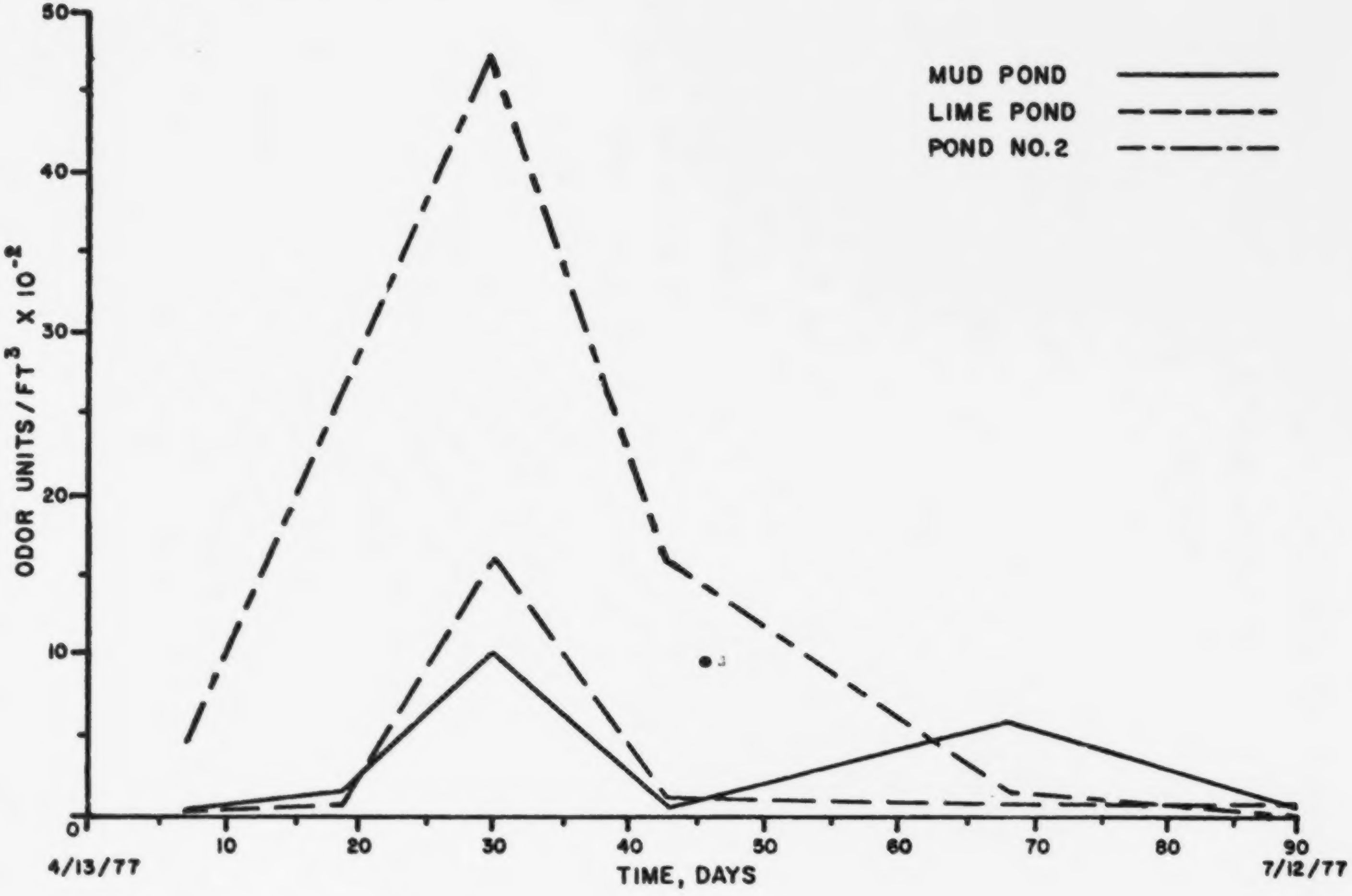


Figure 7. Waste storage ponds - odor vs. time.

TABLE 12. GAS PRODUCTION

Date Sample Recorded	Period of Sample* (days)	Gas Production - ml Mud Pond	 Lime Pond	 Pond #2
4/28/77**	15#	813	589	1,307
5/6/77	8+	65	755	6,918
5/12/77	6	925	8,185	1,502
5/19/77	7	1,630	7,590	11,275
5/26/77	7	17,250	350	8,336
6/2/77	7	17,265	450	11,481
6/9/77	7	1,485	1,860	12,426
6/16/77	7	790	2,705	2,736
6/23/77	7	7,050	2,360	827
6/30/77	7	380	6,700	6,578
7/7/77	7	195	4,440	7,057

* Number of days gas allowed to accumulate

** 4/27/77 for Lime Pond

# 14 days for Lime Pond

+ Four days for Pond 2; nine days for Lime Pond

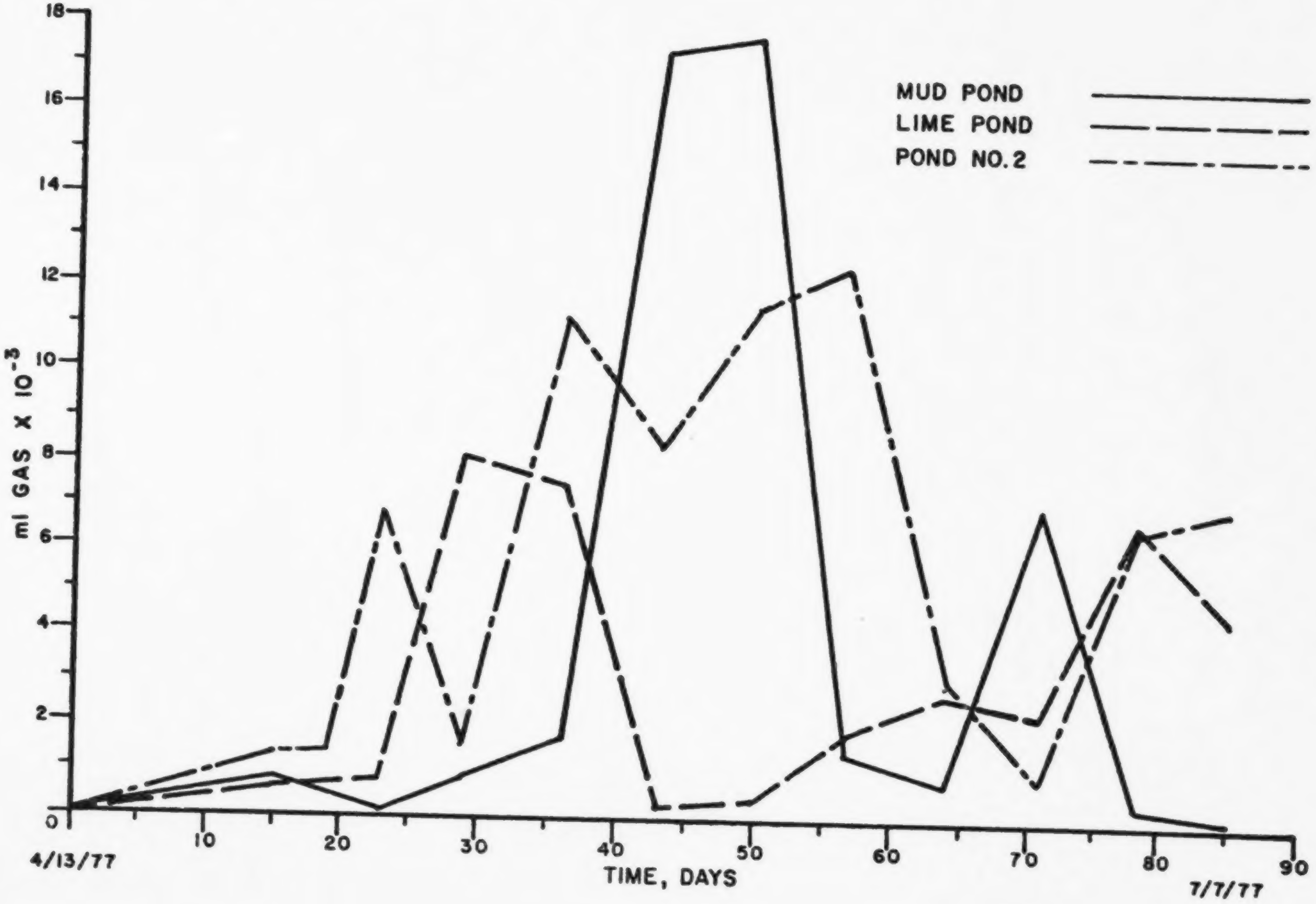


Figure 8. Waste storage ponds - gas production vs. time.

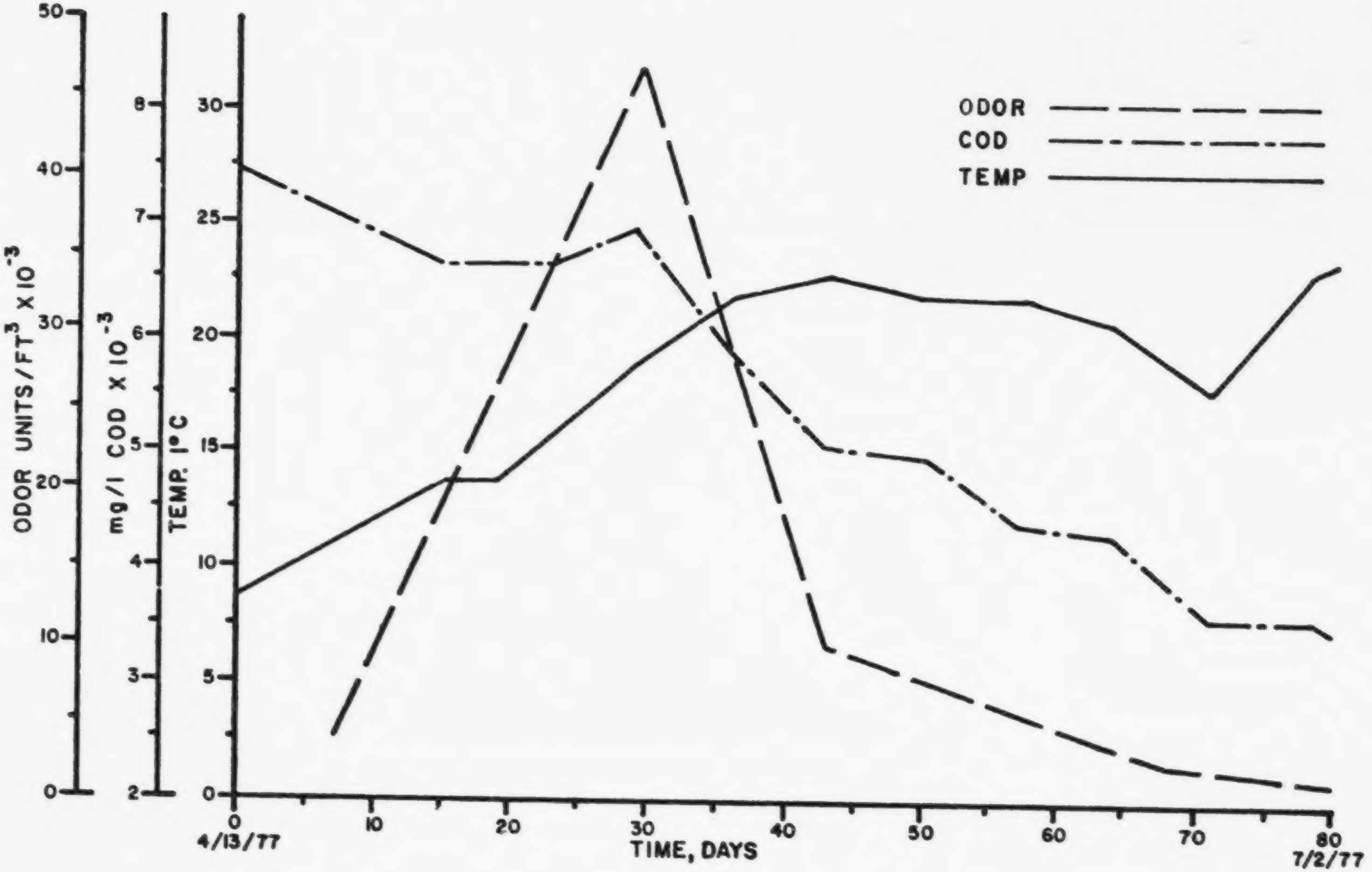


Figure 9. Odor, COD, and temperature vs. time - Pond No. 2.

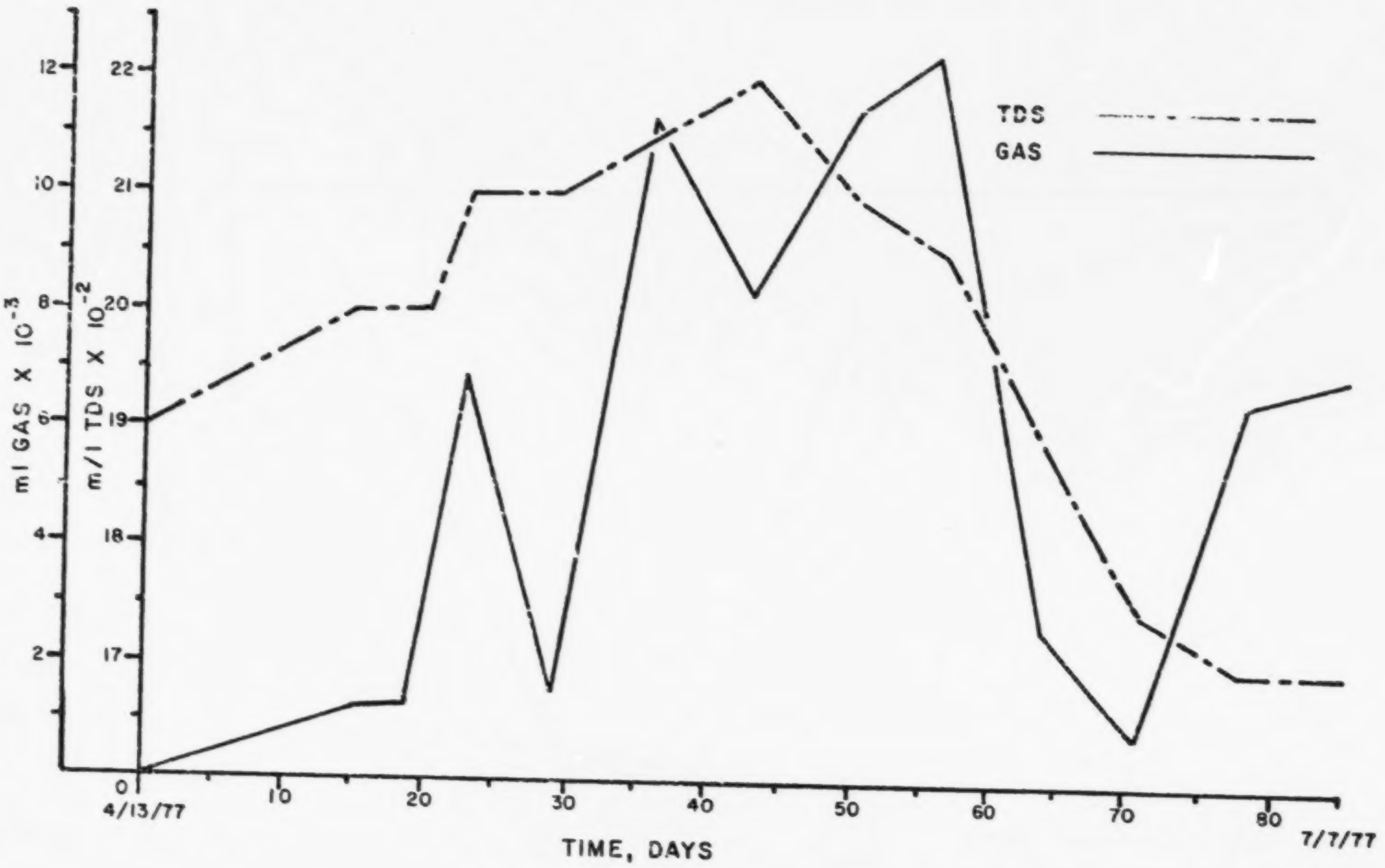


Figure 10. Gas and TDS vs. time - Pond No. 2.

the same parameters in the other ponds.

Although the pH dropped to 6.8 for a few days in one pond, it generally remained above 7.3. A positive correlation does exist for all ponds between odor and pH, and odor and TDS. More odor emanated from the sample sites on the lime pond than from the mud pond. This might be a case of sample site selection or it may be due to the fact that the lime pond was much slower in thawing out and releasing its liquid fraction.

The results of the chemical analyses of the grab samples are shown in Tables 13 and 14. Sulfide and mercaptan compounds in the samples were identified by comparing standard mixture peak retention times to the sample retention times. This method is not absolutely positive for identification purposes. However, unknown peaks in the sample chromatograms having retention times identical to those in the standard mixtures have a high confirmation probability.

The Pond No. 2 condensation sample was lost when the sampling tube was broken. No qualitative or quantitative information was obtained.

Mud pond and lime pond condensation samples indicated methyl sulfide and n-propyl mercaptan at 35°C, and methyl disulfide at 100°C.

Concentrations of methyl sulfide, n-propyl mercaptan, and methyl disulfide were higher in the 100°C sample chromatograms than in the 35°C sample chromatograms. The concentration increases of these compounds from 35°C to 100°C were not proportional in the mud pond and lime pond samples. The sample concentration calculations could have introduced some error in these values.

Comparison of the Teflon bag sample concentrations with the condensate sample concentrations indicates some significant differences, particularly in the lime pond samples. A high concentration of methyl disulfide was found in the 100°C condensate sample, while none was found in the Teflon bag sample. The phenomenon is suspected to have occurred while transferring air samples from the field sampling Teflon bags to the laboratory Tedlar bags, and indicates that transferring air samples should be avoided if at all possible.

The Pond No. 2 Teflon bag samples had the largest concentrations of organic sulfides and mercaptans. The lime pond samples had the largest concentration of hydrogen sulfide. The difficulty lies in translating these values in terms of odor. A number of variables exist: the odor threshold of each component, the partial pressure balance, component boiling points, as well as the unidentified components indicated in the chromatograms. Total peak area integrator counts for the Teflon bag samples were: lime pond - 12,800; mud pond - 26,200; and Pond No. 2 - 27,700. This further indicates that Pond No. 2 had the largest concentration of volatile organic components.

The carbon adsorption method gave no usable data, with the samples being identical to the blank.

TABLE 13. RESULTS OF CHEMICAL ANALYSIS -- MAY 26, 1977 TEFLON BAG SAMPLE

	Mud Pond	Lime Pond	Pond #2
May 26, 1977 Teflon Bag Sample			
Nitrogen - % v/v	78.3	77.9	77.9
Hydrogen Sulfide - ppm	1	L.T. 1*	3
Methane - % v/v	0.02	L.T. 0.01*	1.35
June 20, 1977 Teflon Bag Sample			
Hydrogen Sulfide - ppm	0.03	0.03	0.04
Methane - % v/v	0.01	0.02	0.07

* L.T. = Less than

TABLE 14. RESULTS OF CHEMICAL ANALYSIS -- JULY 12, 1977 TEFLON BAG SAMPLE

	Mud Pond	Lime Pond	Pond #2
Hydrogen Sulfide (H_2S)-ppb*	5	11	6
Methane (CH_4)-ppm	1	1	1
Methyl Sulfide ($(CH_3)_2S$)-ppb	7	2	10
N-Propyl Mercaptan (C_3H_7SH)-ppb	ND	ND	3
Methyl Disulfide ($(CH_3)_2S_2$)-ppb	ND	ND	5

ND = Not Detectable

* The calculated H_2S values were below the minimum detectable limit of 20 ppb for the test, and the accuracy of the reported values are somewhat questionable. The concentrations reported should be used for comparison of sites rather than as true values.

ULTIMATE DISPOSAL OF SOLIDS

The farmer whose fields were treated with the filter cake sludge reported some difficulty in working the ground due to the tendency of the sludge to compact. He also reported, however, that the two parcels had higher wheat yields than the rest of the field. MINN-DAK indicated that the pH of the soil before and after the experiment was not measured, but that the results were encouraging and that further studies may be carried out under the auspices of the Red River Valley Association. No problems have resulted from using filter cake as an embankment and fill material, but this application is limited to local demand for this type of material and must stand the test of time.

SECTION 8

DISCUSSION

This section discusses some of the problems encountered in carrying out the study and summarizes the findings that indicate that the solids handling and dewatering system was not functioning as intended. The odor study results are also discussed. The actual operations of the clarifier and vacuum filter systems are compared to the criteria developed in the ACS study and those used in design. The section closes with discussion of changes that could be considered to improve or augment various components of the total system so that the desired results can be achieved.

DATA COLLECTION

As noted in previous sections, accurate evaluation of the solids handling system was complicated by many factors. The system lacked adequate flow control devices and problems were encountered with the flow meters and stroke counters installed for the study. The filtrate flow meter, after some initial problems attributed to aeration of the liquid, performed well most of the time and produced reliable data. The aeration problem was resolved by moving the meter from the discharge side to the suction side of the filtrate pumps.

The clarifier underflow flow meter, after producing data for a few days, operated erratically and eventually stopped functioning. The instrument was returned to the manufacturer for service, but upon reinstallation at MINN-DAK, it again failed to register flow. It was determined that the solids carried by this liquid caused the meter to malfunction. The meter was removed and returned to the manufacturer.

Sludge pump stroke counters were installed to determine the rate of filter cake production. In reviewing the operating logs, however, it was determined that the sludge displacement data were subject to wide variations depending upon how the effective stroke of the pump cylinder was determined. Different operators used different means to determine what the effective stroke length was. In some instances, the operators recorded the distance to be subtracted from the full stroke, while others recorded an estimated effective stroke.

Difficulties in obtaining actual design information from BMA resulted in much of the analysis being based on calculated data or values assumed from observation and measurement of actual operations.

The Mud House operators were asked to record the opening of the two flow control valves to determine the amount of clarifier underflow being pumped into the mixing tank. It was soon discovered that the operators manipulated these valves frequently, causing the underflow to flow into the mixing tank or to be bypassed to the south lagoon in a random fashion. Several pitfalls were associated with this flow control method, as described in previous sections. Also, no records were kept of what flows were directed to each point, and the operators had no standards to maintain, or guidelines to follow, in deciding whether to filter or to bypass underflow. In general, it can be said that the day crews tried to take in and filter as much underflow as possible and the night shifts preferred to filter straight lime mud. Another factor that limited underflow filtration was that most routine maintenance shutdowns were scheduled during the day shift.

RESULTS - DEWATERING SYSTEM

The process flow data support the conclusion that the filter feed consisted primarily of waste lime mud. The total and volatile solids data show the close relationship between the lime mud and the filter cake, and clearly indicate that the amount of clarifier underflow filtered was almost negligible compared to the amount of lime mud filtered. Lime mud COD values are generally reflected in both the filtrate and the filter cake and, as expected, the clarifier underflow did not exert a significant influence on the filtrate and filter cake COD contents.

The data generally show very low total calcium concentrations in the clarifier underflow and the filtrate compared to substantially higher concentrations in the lime mud and the filter cake. The lime mud contributed most of the total calcium in the filter cake. The dissolved calcium concentrations are within the same order of magnitude for all four streams. This conforms to expectations because of the low solubility of calcium salts.

The bulk density and percent solids data, with the exception of the clarifier underflow, were quite consistent throughout the data collection period. They also show the negligible contribution of solids from the clarifier underflow to the filter cake solids.

RESULTS - ODOR STUDY

Analysis of gas samples from the lime pond, mud pond, and one wastewater pond indicate that methane, hydrogen sulfide, and mercaptans are among the odorous elements of the off-gases.

Although the carbon adsorption method of gas collection yielded no usable data, chromatograms indicated that the lime pond had the largest concentration of hydrogen sulfide and that Pond No. 2 had the largest concentrations of organic sulfides and mercaptans. Total peak area integrator counts also showed that the gases from Pond No. 2 had the highest concentration of volatile organic components.

During the field sampling, it was observed that a greater concentration of odors was detected 18 inches beneath the surface in the mud and lime ponds than at 6 or 12 inches. This field observation, and the results of the chemical analysis showing that different malodorous compounds appear at different temperatures, illustrate that a variety of compounds is present, each released at a certain temperature range. Some compounds, through bacterial action, may appear more than once.

Gas production fluctuated over the 90-day sampling period. Hydrogen sulfide was released during periods of low pH. This indicates that hydrogen sulfide can be controlled by maintaining high pH levels.

Possible causes for the formation of other malodorous compounds were evaluated. The most clearly identifiable changing factor is the addition of process chemicals that may either cause a sustained lowering of pH or bring about the development of mercaptans. Table 15 lists process additives that may be responsible for the generation of various forms of mercaptans.

Further study is required to determine which chemicals are present and how best to control odor formation.

SYSTEM DESIGN AND PERFORMANCE

The design and operation of the MINN-DAK transport water and solids dewatering system incorporated some, but not all, of the findings and recommendations of the ACS study (1). The one major deficiency in the as-built system is the absence of thickening to attain the desired 20 percent or higher solids content in the filter feed.

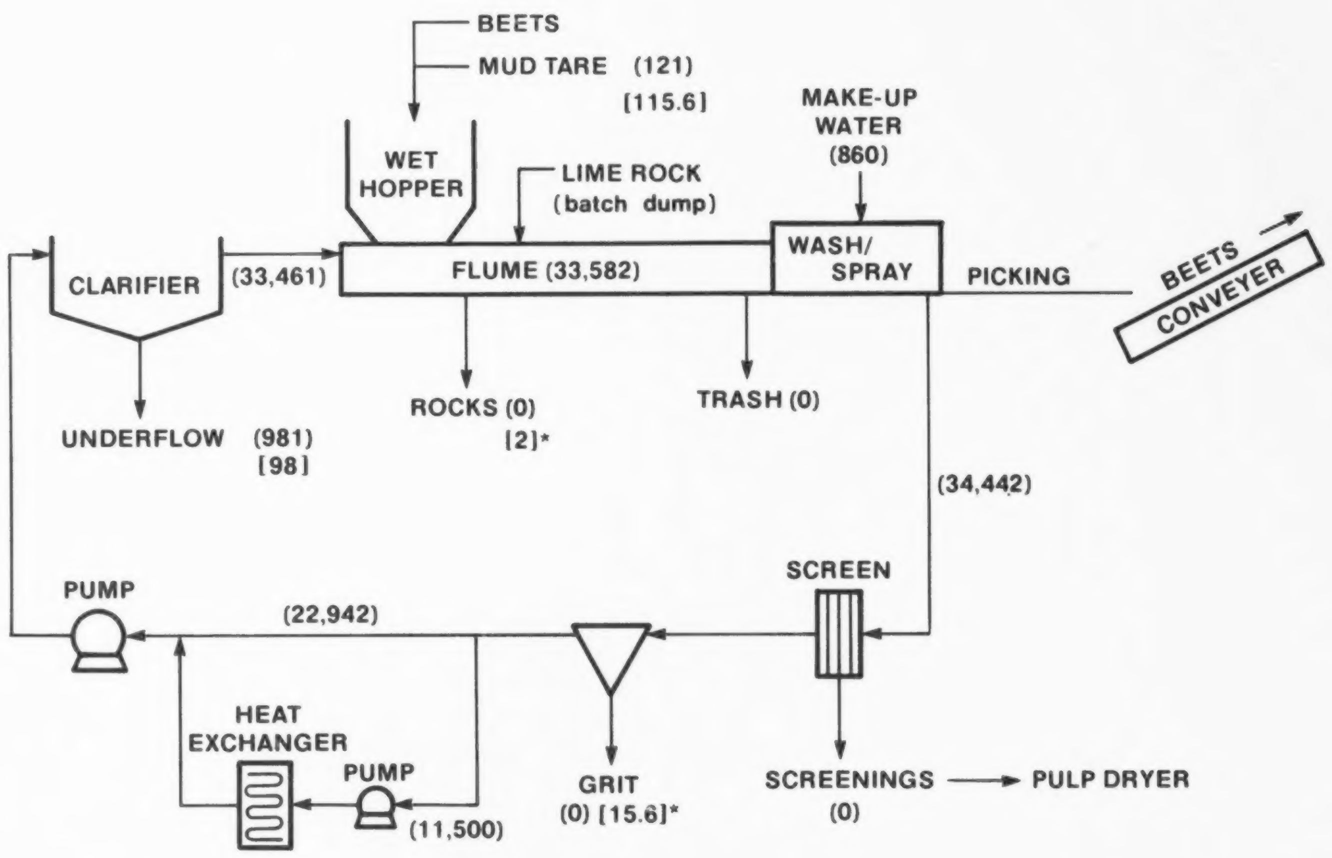
Figure 11 provides a theoretical water balance for the closed loop water transport system. The primary treatment part of the transport water system appears to have been designed in conformance with the ACS study. Table 16 shows design criteria of both the ACS study and those calculated for the MINN-DAK clarifier. Shown also are actual clarifier performance data developed during the 1976-77 campaign operation. Certain ACS study assumptions, e.g., soil tare and underflow solids percent, were used to calculate the MINN-DAK design criteria.

The single negative element in the MINN-DAK clarifier design appears to be a shorter detention time. What Table 16 does not show, however, is that the clarifier recommended in the ACS study is about twice as deep as the MINN-DAK clarifier. Depth is an important consideration in solids settling, consolidation, and storage. Because of a lower soil tare, the actual performance of the clarifier exceeded the design criteria, as shown by lower loadings and higher average underflow solids content and density. However, as discussed earlier, this flow exhibited a wide variation in both volume and characteristics as affected by the sludge withdrawal method.

Two other considerations in the design were deficient with respect to the ACS study recommendations; adequate pH control of the flume water system and polyelectrolyte addition in the clarifier to promote clarification. The pH control method presently in use at MINN-DAK, i.e., dumping lime rock in the beet flume, was not always effective in maintaining the required pH. MINN-DAK experimented with polyelectrolyte addition to the clarifier underflow. This, however, was done in a hit-or-miss manner using mostly old

TABLE 15. PROCESS ADDITIVES AND EVENTUAL DISPOSAL

Chemical	Mud Pond	Lime Pond	Pond #2
Muriatic Acid	No	No	Yes
Sulfamic Acid	No	No	Yes
Calcium Hypochlorite	No	Possibility	Yes
Caustic Soda	No	No	Yes
Foam Oils	Yes	Yes	Yes
Formaldehyde	Yes	Yes	Yes
Microbiocide	Yes	Yes	Yes
Settling Agent	No	Yes	Slight Possibility
Soda Ash	No	No	Yes
Hydrated Lime	Yes	No	Slight Possibility
Water Treatment Chemicals Polyphosphate Disodium Phosphate Anti-foam Sodium Sulfite	No	No	Yes
Lubricants (Grease)	Possibility	Possibility	Possibility
Lubricants (Oils)	Possibility	Possibility	Possibility


BEETS
MUD TARE (121)
[115.6]
WET HOPPER
LIME ROCK
(batch dump)
MAKE-UP WATER
(860)
CLARIFIER
(33,461)
FLUME (33,582)
WASH/ SPRAY
PICKING
BEETS
CONVEYER
ROCKS (0)
[2]*
TRASH (0)
UNDERFLOW (981)
[98]
(34,442)
SCREEN
PUMP
(22,942)
HEAT EXCHANGER
PUMP
(11,500)
GRIT
(0) [15.6]*
SCREENINGS
(0)
PULP DRYER

( ) —Cu. m/day
[ ] —kkg/day soil solids-dry wt.
* —Estimated

NOTE: Based on 1976-77
campaign averages:
beets—3,502 metric ton/day
tare—3.3%

Figure 11. Water and solids balance for beet transport and clarifier systems.

TABLE 16. CLARIFIER DESIGN AND PERFORMANCE

Element	ACS Study	MINN-DAK Design	MINN-DAK Actual
Beets sliced, kkg/day	3,630	4,536	3,500
Dry soil tare on beets, % wt	5	5	3.3
Dry flume solids, kkg/day	182	227	116
Flume water flow rate, cu m/day	32,700	28,800	34,400
Clarifier:			
Surface area, sq m	965	1,520	1,520
Volume, cu m	2,360	1,900	1,900
Dry solids loading, kg/sq m/day	188	149	76
Hydraulic loading, cu m/sq m/day	34	19	23
Hydraulic detention time, hr	1.9	1.7	1.3
Underflow dry solids, % wt	8	8	10
Underflow density, g/ml	1.02	1.03	1.04
Underflow flow rate, cu m/day	2,235	2,730	980

polyelectrolytes. The operators were of the opinion that the polyelectrolyte only added to their operating problems, resulting, in most instances, in total bypass of the clarifier underflow.

The ACS study (1) indicated that the best filtration results were obtained when the lime mud was added to the primary clarifier, followed by secondary thickening and heating of the clarifier underflow. The MINN-DAK design did not provide for thickening and heating of the clarifier sludge, although it did include mixing of lime mud and the clarifier underflow in a mixing tank just before filtration.

The MINN-DAK solids dewatering process, in conformance with ACS study recommendations, included the use of lime mud as a filtration aid. The study had determined that the average 2.5-micron particle size of most Red River Valley soils (Fargo clay) required some form of filter aid and/or heating to achieve reasonable filtration results. MINN-DAK's practical solution was to utilize lime mud as the filter aid. This waste product of the juice purification process has an average particle size of about 25 microns, an average temperature of about 50°C, and is available in sufficient quantities (about 10 percent dry solids of the weight of the beets).

The evaluation of filter performance, under the MINN-DAK system operational conditions, presented some difficulties. Table 17 compares ACS study results with calculated design and actual performance data for the MINN-DAK system. In the ACS study, all of the lime mud (quantities not disclosed) was added to the primary clarifier. The ACS design included secondary thickening of clarifier underflow, and the filter feed characteristics shown reflect the results of secondary thickening and heating. The data presented in this table are consistent with the data presented in Tables 1, 8, 9, and 16.

MINN-DAK operated only one of its two filters to filter essentially all of the lime mud, which had good filtering characteristics. To filter the clarifier underflow effectively and maintain the present volumetric loading of 0.4 cu m/sq m/hr, thickening of the clarifier underflow solids to about 33 percent solids by weight would be required. This flow, when combined with the waste lime flow, would produce a mixture with a density of 1.26 g/ml and a composition of 16 percent clarifier underflow solids, 24 percent waste lime solids, and 60 percent water. The required underflow solids content cannot be achieved in the clarifier as designed under present operating conditions. It is also doubtful that this could be accomplished with the very short detention time (12.5 minutes) recommended in the ACS study for secondary thickening. Thickening studies are required to determine the optimum loadings and detention time to achieve an adequate solids concentration.

The MINN-DAK design includes pumping of the sludge cake to the storage lagoon while the ACS study provided for a belt conveyor to carry the filter cake to a dump truck to be hauled to the disposal site. The ACS study also called for return of the filtrate to the transport water loop. MINN-DAK initially returned the filtrate, but discontinued this practice when the system became overloaded with surplus water. Fresh water input to the

TABLE 17. VACUUM FILTRATION PROCESS DESIGN AND PERFORMANCE

Element	ACS Study *	MINN-DAK Design	MINN-DAK Actual
Flume solids, kg/hr	7,580	9,500	230
Lime mud solids, kg/hr	unk	13,900	13,700
Filter feed volume, cu m/hr	33	44**	23
Filter feed solids, % wt	20	32**	45
Filter feed density, g/ml	1.14	1.74	1.36
Filter feed temperature, °C	25	18	45
Filter area, sq m	126	126	63
Filter yields:			
Dry flume solids, kg/sq m/hr	60	75	4
Total dry solids, kg/sq m/hr	unk	185	216
Volumetric loading, cu m/sq m/hr	0.3	.33	0.4

* All (quantity unknown) waste lime was added to the primary clarifier. Filter feed characteristics are the result of secondary thickening and heating.

** Based on limited data (9)

system is required to give the beets a final rinse.

SYSTEM MODIFICATIONS

There are many areas that need improvement and, with modest capital investment, the system can be improved to provide more efficient operations. Several changes and additions to the existing transport-water solids treatment facilities are described and illustrated in this section. Figure 12 describes a process flow diagram of the system as it would operate should these and other proposed changes and additions be implemented. Figure 13 shows proposed modifications to the lagoon system. Figure 2, showing the Mud House equipment layout without proposed modifications, may be a helpful reference in visualizing the recommended changes.

pH Control System

Maintenance of a high pH level in the transport water system is required to inhibit bacterial activity. A pH of 10 or higher is required to prevent odors, control the growth of bacterial slimes, and enhance the settleability and filterability of the transport water solids (9, 10). The primary pH control method used at MINN-DAK, dumping lime rock in the beet flume, was not always effective in maintaining the required high pH. The installation of an automatic pH monitor and feed system would be a worthwhile addition to the present system.

Clarification/Thickening

It has been reported in the literature (10) that a direct relationship exists between the solids content of the filter feed and the resulting cake. With its shallow depth and relatively low volume, the existing clarifier did not provide enough detention time or storage capacity to promote adequate settling and consolidation of flume solids. Because it was used to thicken the sludge, a function not included in the design, the clarifier was perhaps the single most deficient unit process and weakest link in the system as constructed and operated.

One of the criticisms most often heard from the operating personnel concerned the sludge removal method employed at the clarifier. The operators pointed out that with the present sludge suction lift mechanism, more water was pumped to the Mud House than necessary. This high flow overloaded the hydraulic capacity of the filters and caused most of the underflow to be bypassed. When permitted, a high underflow-to-lime mud ratio decreased the cake solids, caused more frequent filter washings due to blinding, and increased the possibility of the cake freezing in the discharge pipeline due to the lower temperature of the mix.

The solids content of the filter feed must be increased to the level required for adequate filtration results. The ACS study obtained good filtration results using a high-rate thickener that produced a filter feed having 20 percent solids with polymer addition and heating to 90°C. Scoville determined that a filter feed concentration of 20 to 40 percent, obtained by allowing the clarifier underflow to settle over a 24-hour period at 4°C, was

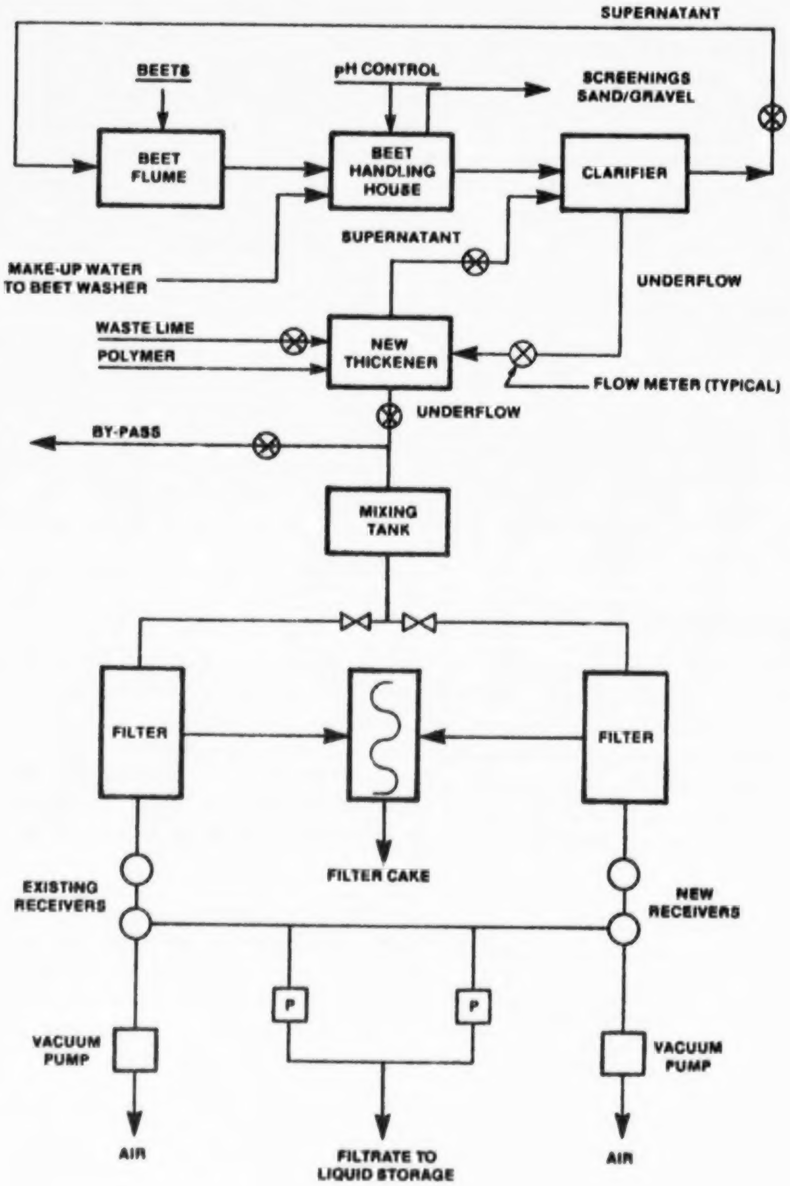

SUPERNATANT
BEETS
pH CONTROL
SCREENINGS SAND/GRAVEL
BEET FLUME
BEET HANDLING HOUSE
CLARIFIER
SUPERNATANT
MAKE-UP WATER TO BEET WASHER
UNDERFLOW
WASTE LIME
POLYMER
NEW THICKENER
FLOW METER (TYPICAL)
UNDERFLOW
BY-PASS
MIXING TANK
FILTER
FILTER
FILTER CAKE
EXISTING RECEIVERS
NEW RECEIVERS
P
P
VACUUM PUMP
VACUUM PUMP
AIR
FILTRATE TO LIQUID STORAGE
AIR

Figure 12. Proposed process flow schematic.

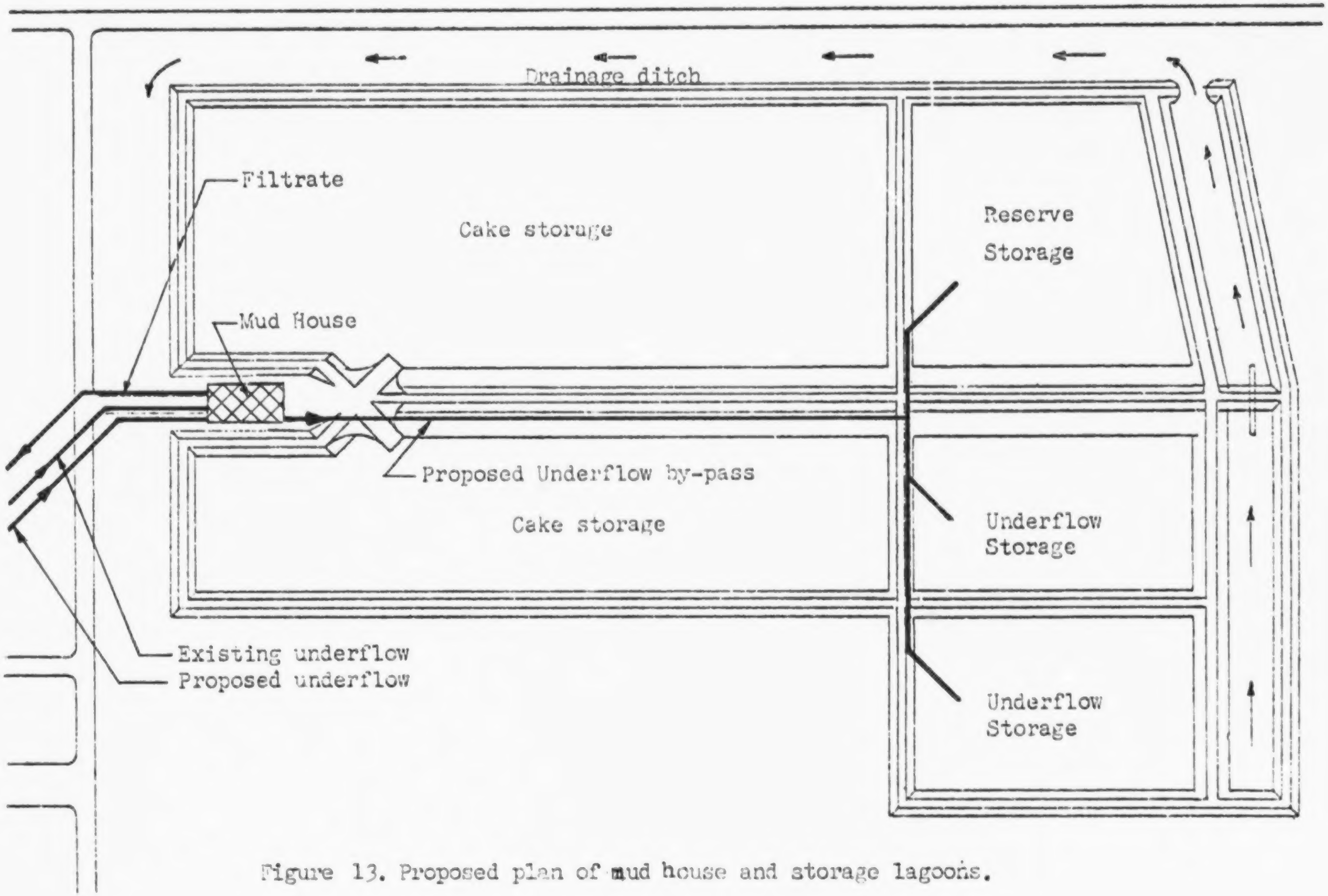

Drainage ditch
Filtrate
Cake storage
Reserve
Storage
Mud House
Proposed Underflow by-pass
Cake storage
Underflow
Storage
Existing underflow
Proposed underflow
Underflow
Storage

Figure 13. Proposed plan of mud house and storage lagoons.

necessary for adequate cake yields (11).

There are two types of thickener that can be used to achieve the desired solids content and characteristics of the filter feed; a conventional gravity thickener relying on the natural settleability of the sludge solids, or a high-rate thickener that would rely on polyelectrolyte addition and heating the sludge as done in the ACS study.

Conventional gravity thickeners are designed on the basis of hydraulic and solids loadings. As a rule, solids loadings govern the design, which varies with the type of influent solids and application. Solids loadings of 100 to 150 kg/sq m/day (20 to 30 lb/sq ft/day) are typically used in the design of units to thicken primary municipal sludge. Units used to thicken water treatment sludges high in calcium carbonate are designed using solids loadings of about 200 kg/sq m/day (40 lb/sq ft/day). Gravity thickeners usually have minimum depths of 3 meters (10 ft) and detention times of up to 24 hours are typically provided for municipal treatment applications (12). The use of conventional thickeners in the treatment of beet flume solids has not been reported in the literature.

The high-rate thickener used in the ACS study had a detention time of 12.5 minutes. The solids loading on this unit was calculated at over 11,000 kg/sq m/day (2,300 lb/sq ft/day). This loading excludes the solids contributed by the addition of the lime mud.

An analysis of the as-built system indicates that the most practical solution at MINN-DAK would probably be to construct thickening and sludge pumping facilities adjacent to the existing clarifier. The main shortcomings in the clarifier design, e.g., detention time, sludge storage capacity, and sludge withdrawal method, can be minimized by designing a thickener for adequate detention time at a maximum sludge withdrawal rate.

Another factor that must be considered is the point at which the lime mud is added. The ACS study determined that the best filtration results were obtained when lime mud was added to the clarifier. If this were done at MINN-DAK, the lime mud solids would at least double the solids loading on the clarifier and would add to the solids storage and handling problems presently experienced there. If a thickener were added, the additional solids or volume of the lime mud stream should be included in the calculations of the thickener dimensions because the lime mud would have to be pumped directly to the thickener. Preliminary indications are that a conventional gravity thickener would have a higher capital cost than the high-rate thickener, but the former would be more economical to operate. Costs must be determined through pilot studies, however.

The operation of the existing clarifier would remain essentially unchanged. The supernatant would continue to flow to the beet flume and the sludge would be pumped to the new thickener. New positive displacement pumps and a new pipeline should be installed to pump the thickener underflow to the Mud House. Positive displacement pumps are widely used to pump heavy sludges and industrial slurries. Several pluggings of the existing 10.2 cm (4-inch) pipeline occurred during the study and past campaigns. A new larger diameter pipeline might minimize interruptions due to plugging. The existing pipeline would be retained for use during maintenance to keep the new pipeline free of obstructions. Heat-tracing and insulating the pipeline would raise the temperature and reduce the viscosity of the sludge, making it more fluid before pumping.

A small local control room should be provided at the new pump station, with alternate control provided remotely from the Mud House. A Parshall flume or similar type of flow meter would be required to record the flow of the clarifier supernatant to the beet flume. Flow meters of appropriate types should be installed on the following process flows: clarifier underflow to the thickener; waste lime flow to the thickener; thickener supernatant to the clarifier; and thickener underflow to the Mud House. Equipment alarms, a sludge density meter, and a thickener sludge-bed depth monitor should also be installed. Additional flow control and monitoring requirements are discussed in the proposed modifications to the Mud House equipment. The type of thickener used in the new system would determine the operating requirements at this remote location. A telephone should be installed to maintain communications between the Mud House and the clarifier/thickener facility.

Mud House

The Mud House personnel attempted to operate both filters simultaneously on several occasions. After a few hours, however, it became necessary to revert to the standard plant procedure of operating a single filter. Several design deficiencies were responsible for this situation: the excessive volume of diluted clarifier underflow admitted; the common vacuum and filtrate extraction system; and the inability of the sludge pumps to handle the sludge quantities produced by the two filters. The problem of excessive amounts of dilute clarifier underflow has been addressed previously.

With respect to the common vacuum and filtrate extraction system, Figure 2 shows the two receivers connected in series while the filters and the vacuum pumps had parallel arrangements. The filters, each having cloths of different age, state of repair, or degree of cleanliness, responded differently to the common vacuum application, resulting in unequal cake production rates and qualities. Although there were duplicate vacuum pumps, receiver tanks, and filters, it was not possible to operate the two filters because of the present piping arrangement and the behavior of the filters. This resulted in one of the filters being shut down.

Pumps and similar equipment are normally designed as redundant units for standby service. It is difficult, however, to justify the installation of a filter of the size and cost of those used at the Mud House for redundancy. These filters were designed to work concurrently during peak sludge production. They could be operated simultaneously by adding a few linear feet of pipe, a few strategically located control valves, two additional receivers and, if required, some back-up equipment. It is unlikely that the filtrate pumps need replacement or that a third vacuum pump would be required for standby service. These expenditures would, in any case, be very modest when compared to the sizable capital investment already made in the dewatering facility.

Two filters operating simultaneously would overtax the capacity of the sludge pumps. These pumps, although rugged and reliable, have been the subject of constant attention and maintenance. The practice of trickling water onto the filter cake to condition it for pumping defeats the dewatering process. Also, the extreme North Dakota winters make pumping a heavy sludge through an exposed pipeline a very risky proposition. For these reasons, the pump and pipeline method of transporting the filter cake from the Mud House to the lagoons should be abandoned and in its place a solids-handling system, such as a conveyor, should be designed and installed.

The operation of the Mud House can be upgraded by installing instruments to control and monitor process flows, developing procedures for recording daily operating data, and clearly defining the operators' responsibilities. An accounting must be made of all process influent and effluent flows. To do this, flow meters should be installed on the filtrate, the new thickener underflow, and the underflow bypass pipelines. A scale to monitor the production of filter cake could also be installed in conjunction with the proposed conveyor system. However, if all other process flows are adequately accounted for, this last item may be redundant. The volume of sludge accumulated in the lagoons on a weekly, bi-weekly, or monthly basis could be monitored as an alternative to the scale.

An adequately sized, furnished, and isolated control room should be provided. This control room should be conveniently located within the Mud House and should house a central control panel showing all process flows and other equipment monitors required for the operation of the entire system.

Sludge Lagoons

The two-lagoon system should be modified for consistency with some of the process design changes recommended above. The underflow bypass should be piped to the farthest cells in the new layout to minimize the distance that the dewatered cake must be conveyed. The dewatered cake should be stored, with respect to the Mud House, in the nearest half of the south lagoon and the nearest two-thirds of the north lagoon. The most distant third of the north lagoon should be held in reserve for either underflow or cake storage. The dikes for this new system can be constructed using the dried sludge cake from previous campaigns. Methods for collecting and removing free water should be developed to avoid odor nuisance due to anaerobic conditions.

ULTIMATE DISPOSAL OF SOLIDS

As far as reclaiming the clarifier underflow solids, MINN-DAK indicated that the management is confident of its ability to demonstrate to the growers that this sludge is suitable for soil cultivation purposes. Because of the obvious economic impact of transporting sludge, the water content of the sludge becomes a very important factor in the management of this material.

Collection of information from local growers about ultimate disposal practices or possibilities and their technical and economic implications was outside the scope of this study. Additional research is needed to evaluate the alternatives available for ultimate disposal.

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APPENDIX A

ADDITIONAL DATA TABLES

TABLE A-1. FILTRATE FLOW RATE DATA

Date	Flow Rate liters/min.	Operating hours	Composite liters/min.-hours
12/13/76	85.2	14	1,193
12/14/76	90.5	10	905
12/16/76	98.0	8	784
12/17/76	101.1	18	1,820
12/19/76	135.5	12	1,626
12/29/76	186.6	13	2,426
12/30/76	115.8	16	1,853
12/31/76	103.3	22	2,273
01/02/77	136.3	24	3,271
01/03/77	74.2	8	594
01/04/77	102.2	8	818
01/05/77	138.9	10	1,389
01/06/77	83.3	6	500
01/07/77	90.5	4	362
01/07/77	133.6	12	1,603
01/08/77	59.8	16	957
01/09/77	98.0	14	1,372
01/10/77	88.9	5	444
01/11/77	179.0	22	3,938
01/12/77	128.7	7	901
01/13/77	78.0	8	624
Totals	--	257	29,653
Weighted Avg.	115.4	--	--

TABLE A-2. CLARIFIER UNDERFLOW TO VACUUM FILTERS

	Clarifier Pump Motor Discharge vs % Load							
East Valve Opening* cm	30%		32%		34%		36%	
	l/min	% Total	l/min	% Total	l/min	% Total	l/min	% Total
6.4	0	0	0	0	0	0	0	0
5.7	0	0	0	0	0	0	0	0
5.1	0	0	0	0	75	10	115	15
4.4	0	0	95	15	190	25	225	30
3.8	0	0	230	40	300	45	340	45
3.2	95	20	380	60	395	60	455	60
2.5 (1 in)	210	40	455	75	492	70	550	70
1.9	360	70	530	90	585	85	645	85
1.3	510	95	570	95	645	95	700	95
Closed	530	100	605	100	680	100	755	100

* For location, see Figure 2.

TABLE A-3. INSTANTANEOUS pH AND VISCOSITY DATA

Instantaneous pH (12-14-76)

Time	Clarifier Underflow	Filtrate
7:30 p.m.	10.0	8.8
8:30 p.m.	9.6	9.0
9:30 p.m.	10.3	9.4
10:30 p.m.	10.1	9.4
11:30 p.m.	10.0	8.9

Viscosity

Date	Clarifier Underflow		Waste Lime		Filter Cake	
	Visc. cps	Temp. °C	Visc. cps	Temp. °C	Visc. cps	Temp. °C
12/22/76	-	-	1,480	26	-	-
12/22/76	-	-	1,320	25	-	-
12/28/76	20	22	1,100	23	24,000	22
01/06/77	15	25	660	25	24,000	24
01/10/77	35	25	740	25	12,000	25
01/14/77	60	23	720	26	46,000	23
01/17/77	50	24	1,900	25	31,000	23
01/18/77	45	25	1,750	24	24,000	23
Average	40	-	1,210	-	27,000	-

TABLE A-4. SUPPLEMENTARY DATA

Date	Beets Processed Metric Tons	CaO Consumed Metric Tons	Clarifier Pump % Motor Load	Ambient Temp. (°C) High	Ambient Temp. (°C) Low
11/09/76	3,822	98	33.3	9	-3
11/10/76	3,765	100	34.7	-2	-7
11/11/76	3,443	76	36.4	-6	-14
11/12/76	3,711	89	36.9	-5	-10
11/13/76	3,729	94	35.5	2	-13
11/14/76	3,725	93	36.8	4	-16
11/15/76	3,274	93	32.3	4	-13
11/16/76	3,342	100	33.8	7	-13
11/17/76	3,261	93	32.0	8	-6
11/18/76	3,312	85	39.1	12	-6
11/19/76	3,728	98	31.4	5	-6
11/20/76	3,418	83	37.5	3	-10
11/21/76	3,652	93	34.7	1	-4
11/22/76	3,416	91	35.0	-3	-11
11/23/76	3,405	89	34.8	-4	-9
11/24/76	2,898	72	35.8	4	-7
11/25/76	2,442	65	35.5	3	-3
11/26/76	2,732	64	32.8	1	-12
11/27/76	3,455	92	35.8	-11	-22
11/28/76	3,668	90	33.5	-13	-24
11/29/76	3,565	81	34.8	-14	-19
11/30/76	3,634	93	33.1	-9	-21
12/01/76	3,618	88	34.6	-9	-18
12/02/76	3,664	87	34.9	-12	-26
12/03/76	3,160	84	35.4	-8	-17
12/04/76	3,705	93	35.5	-3	-13
12/05/76	3,282	93	34.4	-8	-19
12/06/76	3,543	93	34.9	-21	-26
12/07/76	3,198	90	35.0	-16	-24
12/08/76	3,432	92	32.4	-14	-25
12/09/76	3,795	95	33.7	-8	-15
12/10/76	3,669	93	34.3	-9	-24
12/11/76	3,652	91	36.2	2	-22
12/12/76	3,846	94	35.1	-9	-18
12/13/76	3,402	82	33.4	-3	-18
12/14/76	3,518	89	31.7	4	-7
12/15/76	3,524	94	34.4	2	-7
12/16/76	3,549	92	34.5	7	-7
12/17/76	3,622	87	34.6	3	-6
12/18/76	3,200	87	34.6	4	-7
12/19/76	3,654	102	33.0	1	-13
12/20/76	3,526	87	34.0	-12	-22
12/21/76	3,283	90	35.5	-5	-21
12/22/76	3,533	102	34.4	1	-12
12/23/76	2,915	84	32.0	-8	-22
12/24/76	3,471	98	32.3	-2	-15
12/25/76	3,748	103	32.6	-4	-13
12/26/76	3,584	97	32.0	-4	-19
12/27/76	3,351	99	31.6	3	-17
12/28/76	3,431	99	31.9	-15	-22
12/29/76	3,554	100	33.0	-18	-28
12/30/76	3,073	90	32.6	-25	-33
12/31/76	3,634	99	38.2	-22	-28
01/01/77	3,539	92	39.6	-13	-29
01/02/77	3,676	93	40.0	-11	-25
01/03/77	3,657	87	32.4	-18	-26
01/04/77	3,815	92	30.7	-14	-22
01/05/77	3,378	83	32.7	-13	-20
01/06/77	3,233	91	35.5	-13	-18
01/07/77	3,497	83	30.2	-16	-24
01/08/77	3,550	85	32.2	-17	-31
01/09/77	3,402	89	31.9	-23	-37
01/10/77	2,467	64	33.9	-27	-31
01/11/77	3,477	89	33.8	-22	-28
01/12/77	3,318	86	32.1	-18	-36
01/13/77	3,258	81	30.7	-13	-21
Average	3,452	91	33.6	-7	-18
Total	227,800	--	--	--	--

TABLE A-5. MINN-DAK'S 1976-1977 CAMPAIGN WASTEWATER INVENTORY

	Quantity (cu m)	Flow Rate* (cu m/day)
Extracted from beets	45,420	388
Factory processes (condenser, clean-up, etc.)	174,110	1,488
Transport water system		
Filtrate	19,188	164
Clarifier underflow lagoon**	43,290	370
Filter cake lagoon#	2,691	23
Mud House, runoff, etc.##	10,062	86
Totals	294,761	2,519

* Average spread over a 117-day campaign.

** Assumes 40 percent of clarifier underflow lagoon contents becomes free water. The average flow rate bypassed was 926 cu m/day.

# Assumes 6 percent of the filter cake volume becomes free water. The average filter cake solids was 382 cu m/day before dilution water was added for pumping.

## Includes filter wash and Mud House clean-up water.

APPENDIX B

MUD HOUSE LOG SUMMARY

In the following day-to-day report on the Mud House activities, the initial paragraph will summarize sample collection information and any highlights of special events taking place on that day. Sampling periods are designated from 1 through 12, with sampling period No. 1 corresponding to the 9 a.m. collecting period. Missing sampling periods will be identified and will be followed by reasons, if any, entered in the log. The second paragraph will summarize any flow data, actual or estimated from log entries, and the third paragraph will summarize data on the filters' operation. The interpreter of this log will, from time to time, offer his comments in parentheses or a fourth paragraph at the end of the day.

This format will be abandoned starting with the January 7, 1977, entry when data will be entered following the chronological order of events.

11/9/76 Began monitoring and sample collection at the Mud House. The south filter was down indefinitely waiting for parts ordered from Germany to rebuild the air blow-off unit that blew up when an operator attempted to run the filter with too much air in it. Full sampling at all stations.

No data were entered on clarifier underflow distribution.

The north filter operated at 3 min, 42 sec per revolution, submergence between full and half-full, and vacuum of 8 to 12 inches Hg.

11/10/76 Samples 1, 3, and 4 were not taken: polymer tests conducted by MINN-DAK.

No data were entered on clarifier underflow distribution.

The north filter operated at 3 min, 42 sec per revolution, submergence between 3 and 16 inches from the top, and vacuum of 4.5 to 10.5 inches Hg.

11/12/76 Samples 5 through 12 were not taken: the Mud House was shut down because of a broken binding wire on the north filter.

No data were entered on clarifier underflow distribution.

The north filter operated, from 8 a.m. to 4 p.m., at 3 min and 42 sec per revolution, submergence between full and one-third full, and vacuum of 5 to 10 inches Hg.

11/14/76 Full sampling at all stations.

No data were entered on clarifier underflow distribution.

The north filter operated at 3 min, 42 sec per revolution, submergence between full to 3.5 inches from the top, and vacuum of 3 to 9 inches Hg.

11/15/76 Sample No. 8 was not taken but no reason was given.

Inconclusive data on clarifier underflow distribution were entered.

The north filter operated at 3 min, 42 sec per revolution until 4:00 p.m. at which time the speed changed to 2 min, 30 sec per revolution, submergence between full and 8.5 inches from the top, and vacuum of 5 to 11 inches Hg.

11/16/76 Sample No. 2 was not taken: the filter was shut down to wash the drum. A high filtrate temperature of 32°C and a low vacuum of 6 inches Hg, at 3:00 a.m., was reported as the result of "cutting," mostly waste lime.

Inconclusive data on clarifier underflow distribution were entered.

The north filter operated at 2 min, 30 sec per revolution, submergence between full and 21 inches from the top, and vacuum of 5 to 11 inches Hg.

11/17/76 New log sheets were put into effect. Samples No. 4 and 5 were not taken: the filter was shut down to repair the agitator bearing; then the plant was shut down for lack of waste lime; tried to filter underflow only but the filter clogged and had to be washed. The third shift reported unable to take much underflow into the mixing tank because of the high pumping rate required to lower the clarifier mud level (this made the underflow too thin).

The first shift reported 75 percent underflow bypass; the second shift's entries were inconclusive; the third shift reported about 55 percent bypass. (These estimates were questionable; only total bypass entries are considered reliable.)

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence mostly full to half-full, and vacuum of 8 to 12 inches Hg.

11/18/76 Samples No. 5 and 11 were not taken: shut down the filter to wash the cloth and to reset the cutting blade; shut down the filter at 5:00 a.m. to repair binding wire and to wash the cloth.

The underflow flow meter was installed and started at 11:00 a.m.; the calculated flow rate was 57 gpm for 21 hours of operation.

Percentages of underflow bypassed were reported as follows: 75 by the first and second shifts and 80 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between full and 18 inches from the top, and vacuum of 8 to 11.5 inches Hg.

11/19/76 Full sampling at all stations.

The underflow flow rate was calculated at 105 gpm for 22 hrs of operation. The reported bypassed percentages were: 80 by the first shift; 75 by the second shift; and 80 by the third shift.

The north filter operated continuously at 2 min, 30 sec per revolution, submergence from 48 inches below the top for the first 8 hours to mostly full for the balance, and vacuum of 4 to 11 inches Hg.

Comment: A trouble-free and smooth running working day attributed to filtering mostly waste lime.

11/21/76 Samples No. 4 and 11 were not taken: shut down the filter to repair agitator; shut down again at 5:00 a.m. for unspecified repairs.

The underflow flow rate was calculated at 57 gpm for 22 hrs of operation. Bypassed percentages were reported as follows: 70 by the first and second shifts; 65 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between full and 21 inches from the top, and vacuum of 5 to 10 inches Hg.

Comment: The filtrate temperature dips following both shutdowns as the liquid in the filter pan cools off without fresh input of hot waste lime.

11/22/76 Sample No. 1 was not taken: the filter was shut down for washing.

The underflow flow meter yielded a calculated flow rate of 58 gpm for 20 hrs of operation. Bypassed underflow percentages were reported as follows: after an initial 3-hr total bypass, only 10 percent was bypassed during periods 2 through 6 (this shows in the low filtrate temperature of 20°C but it is doubtful that the amount filtered is as high as the estimate indicates); 60 percent was bypassed for the balance (this includes a zero bypass 2-hour period).

The north filter operated continuously from 11:00 a.m., at 2 min, 30 sec per revolution, submergence from full to three quarters full, and vacuum of 5 to 11.5 inches Hg.

11/23/76 Samples 1, 7, and 8 were not taken: shut down the filter to wash the cloth during period 1; no explanation was given for shutdown during periods 7 and 8. Began monitoring the temperature of the waste lime at the factory.

The underflow meter stopped recording flow and went into steady fault condition. Bypassed underflow percentages were reported as follows: 50 by the first shift; 75 by the second shift; 25 by the third shift (no underflow appears to have been taken, however, as evidenced by the high filtrate temperature).

The north filter operated at 2 min and 30 sec per revolution, submergence between full and 28 inches from the top, and vacuum of 5 to 11 inches Hg.

Comment: Estimates of the percent of underflow bypassed vary from operator to operator. Actual amounts of underflow being filtered are suspected to be only a fraction of the reported estimates.

11/24/76 Full sampling at all stations, although the plant was shut down between sampling hours to wash the filter, patch the cloth, and switch the sludge pumps.

The underflow flow meter was out of service. Bypassed underflow percentages were reported as follows: 40 by the first shift; 75 by the second shift; and 60 by the third shift.

The north filter operated at 2 min and 30 sec per revolution, submergence between full and 12 inches from the top, and vacuum of 4 to 11.5 inches Hg.

11/25/76 Sample No. 2 was not taken: shut down the filter to wash the cloth. The second and third shifts reported that little waste lime was being delivered from the factory.

The underflow flow meter remains out of service. Bypassed underflow percentages were reported as follows: 35 by the first shift; and 90 by the second and third shifts (including 8 hrs. of total bypass).

The north filter operated at 2 min and 30 sec per revolution, submergence between full and 30 inches from the top, and vacuum of 2 to 11 inches Hg.

11/26/76 Sample No. 2 was not taken: the underflow line plugged at 8:10 a.m.; the line was cleared by 9:40 a.m. but, because of large amounts of sand in the clarifier, the filter was shut down for washing.

No data on the underflow flow meter were entered. Bypassed underflow percentages were reported as follows: 50 by the first shift; 40 by the second shift, which included a zero bypass period; 50 by the third shift.

The north filter operated, as noted above, at 2 min and 30 sec per revolution, submergence between full and 12 inches from the top, and vacuum of 4 to 11 inches Hg.

11/28/76 No samples were collected during the first and second shift, but no reasons were given.

The third shift reported bypassing 60 percent of the underflow.

The north filter operated, except as noted above, at an unknown speed, submergence kept at half-full to repair bearing seal on rim, and vacuum of 6 to 8 inches Hg.

11/29/76 Several samples were not taken as follows: Period 1--no reason given; Period 4--repaired a broken valve on the sludge pump; Periods 6 through 9--the clarifier was shut down to replace the casing on the clarifier pump.

The clarifier was shut down during most of the first and second shifts; the third shift reported 60 percent bypass (total bypass is suspected as clarifier temperature remained unchanged).

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence full to half-full, and vacuum of 3 to 9 inches Hg.

11/30/76 Underflow samples 4 through 9 were not taken: the underflow line plugged. The plant continued operating, filtering waste lime except for washing of the drum and patching of the cloth during period No. 9.

The underflow meter was returned to the manufacturer. When flow from the clarifier was restored, the third shift reported 40 percent bypass for 6 hrs.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between three-quarters and half-full due to leaks around main bearings, and vacuum of 5.5 to 8.5 inches Hg.

Comment: Today's filter cake and filtrate samples had virtually no underflow contribution.

12/1/76 Underflow samples No. 3, 6, 9, and 10 were not taken: the clarifier underflow line plugged but filtration was continued. The filter was shut down to wash the drum during period No. 6.

Bypassed underflow percentages, when available, were reported as follows: 50 by the first shift, 75 by the second shift, and 100 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between 5 and 18 inches from the top, and vacuum of 5 to 10 inches Hg.

12/2/76 Samples 3, 4, and 10 were not taken: the filter was shut down to clean the filter cloth and patch the drum cover.

Bypassed underflow percentages were reported as follows: 90 by the first shift; 20 by the second shift (this was corrected: initial entries indicate 80 instead of 20; this operator may have estimated the fraction "in" rather than "out"); 45 by the third shift (75 using same argument indicated above).

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between 3 and 18 inches from the top, and vacuum of 5 to 9.5 inches Hg.

12/3/76 Full sampling at all stations throughout the day.

The average underflow bypass was reported at 30 percent for the day (all shifts appear very even).

The north filter operated at 2 min, 30 sec per revolution, submergence from full to half-full, and vacuum of 5 to 8 inches Hg.

12/5/76 No samples were taken during the second shift, although no reasons were given.

Bypassed underflow percentages were reported as follows: 25 by the first shift (for two periods only; the other two are illegible-obliterated); and about 25 by the third shift.

The north filter operated at 2 min, 30 sec per revolution, submergence from full to two-thirds full, and vacuum of 4 to 8 inches Hg.

12/6/76 Six samples were not taken as follows: 2 and 3 to repair the polymer pump; 6 through 9 to rewire the polymer pump. (The filter was shut down 12 hrs.)

Bypassed underflow percentages were reported as follows: 30 by the first and second shifts; 45 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between full and 7 inches from the top, and vacuum of 2 to 9 inches Hg.

12/7/76 The clarifier underflow line was reported plugged at 9:00 a.m. but there was full sampling at all stations.

Bypassed underflow was reported at 25 percent throughout the day.

The north filter operated at 2 min, 30 sec, at full submergence except during the first and the last two periods when it ran half-full because of a leak in the west side packing, and vacuum of 3 to 8.5 inches Hg.

12/8/76 Sample No. 3 was not taken: the Mud House was shut down to wash the drums.

Bypassed underflow percentages were reported as follows: 45 by the first shift; 35 by the second shift; and 30 by the third shift. (These estimates appear very conservative.)

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, at near full submergence except for three periods, and vacuum of 4 to 9 inches Hg.

12/9/76 Sample No. 1 was not taken: the filter was shut down to clean the drum.

Except for the initial total bypass period, the reported underflow bypass was held steady at 25 percent throughout the day.

The north filter operated, except as noted above, at 2 min, 30 sec, submergence full to half-full, and vacuum of 3 to 9 inches Hg.

12/10/76 Sample No. 11 was not taken: the filter was shut down to wash the drum.

Bypassed underflow percentages were reported as follows: 25 by the first and second shifts; and 50 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec, submergence between full and half-full, vacuum of 2 to 10 inches Hg.

12/12/76 Sample No. 2 was not taken: the filter was shut down to clean the drum.

Bypassed underflow percentages were reported as follows: 60 by the first shift; 25 by the second and third shifts. (Very high filtrate temperatures, 29°C to 36°C, contradict these estimates.)

The north filter operated except as noted above, at 2 min, 30 sec, at mostly full submergence except for one half-full period and vacuum of 4 to 8.5 inches Hg.

12/13/76 Samples No. 9 and 10 were not taken, but no reason was given.

The filtrate meter was installed and started at 11:00 a.m. The filtrate flow rate was calculated at 22.5 gpm for a 14-hour operating period. Bypassed underflow percentages were reported as follows: 20 by the first and second shifts; near zero by the third shift (a high filtrate temperature, 33°C, contradicts the third shift's estimate).

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence full to half-full, and vacuum of 2 to 8 inches Hg.

12/14/76 Samples No. 2 and 6 were not taken: first the Mud House was shut down to wash the drum, switch mud pumps, and patch holes in the cloth; shut down a second time to clean the drum. Stroke counters were installed on the sludge pumps.

The filtrate flow rate was calculated at 23.9 gpm for 10 selected hours of operation.

Bypassed underflow percentages were reported as follows: 55 by the first shift; 65 by the second shift; and 40 by the third shift.

The north filter operated, except as noted above, at 2 min, 30 sec per revolution, submergence between full and half-full, and vacuum of 4 to 8.5 inches Hg.

12/15/76 The first six samples were not taken: the Mud House was shut down because of a broken binding wire on the north filter drum. The south filter was started for the first time. The sludge pump was repaired during the shutdown.

The filtrate flow rate was calculated at 8 gpm (no good; too low). A 25 percent underflow bypass was reported for the remainder of the day.

The south filter operated from 9:00 p.m. at 2 min, 41 sec per revolution, submergence full to half-full, and vacuum of 4 to 9 inches Hg.

12/16/77 New log sheets were started. Sample No. 6 was not taken: the Mud House was shut down to clean the drum.

The filtrate flow meter went into fault and empty conditions during the first two periods and was adjusted; the flow rate was calculated at 25.9 gpm for 8 hrs of operation; the meter went into fault condition again during the last period. Underflow was taken in for about 3 hours during the first shift and for about 2 hours during the second and third shifts, as determined by the lagoon bypass valve log put into effect today.

The south filter operated, except as noted above, at 2 min, 41 sec per revolution, submergence full to 6 inches from the top, and vacuum of 5 to 11.5 inches Hg. (The filter speed will no longer be recorded in the log because this speed is maintained throughout the campaign; only changes in this speed will be recorded in the log.)

Comment. A log to record valve stem length was initiated on this day. Without knowledge of the instantaneous rate of flow, however, the actual distribution cannot be estimated. The criteria for determining the estimated time (not flow rate) during which underflow was taken inside is an east valve opening of 2 inches or less.

12/17/76 Sample No. 1 was not taken: the filter was shut down to clean the drum. Sludge was sent outside for 5 minutes at 10:25 a.m. to fix an oil leak in the pump.

The level in the filtrate-air receiver was adjusted to keep air out of the filtrate line which has been causing the filtrate flow meter to go into fault; the filtrate flow rate was calculated at 26.3 gpm for 22 hours of operation. Underflow was taken in for about 2 hours during the first shift, and for about 1 hour each during the second and third shifts.

The south filter operated, except as noted above, at submergence between 2 and 12 inches from the top, and vacuum of 6 to 11.5 inches Hg.

12/18/76 Today was not a scheduled sampling day. Underflow was taken in for about 1 hour each during the first and second shifts; apparently none was taken in during the third shift. The third shift helper did not show up. Problems with gravel from the clarifier were reported as of yesterday.

12/19/76 Full sampling at all stations. Soap, from washing oil off the filter cloth, caused the filtrate to foam, entrapping air and making the flow meter go into fault. A new cloth was put on the north filter drum. The sludge pump counter could not be read.

The filtrate flow rate was calculated at 35.8 gpm for 12 hours of operation. Underflow was taken in for about one-half hour during the first shift, and for about three hours during the second shift; no information was recorded by the third shift.

The south filter operated at submergence between full and half-full, and vacuum of 4 to 9 inches Hg.

12/20/76 Samples No. 2, 3, and 7 were not taken; the filter was shut down to wash and change the drums, and to fix the sludge pump; the plant was shut down again to switch the drums. The west sludge pump was repacked; the east sludge pump has a cracked hydraulic cylinder.

Underflow was taken in for about 4 hours each during the first and second shifts; the third shift again failed to record valve settings.

The filtrate flow meter went into a steady fault condition. (No reliable data were produced.)

The north filter operated until switched, as noted above, at submergence between full and half-full, and vacuum of 3 to 9 inches Hg. The south filter operated from period 8 on, as noted above, at submergence between full and 12 inches from the top, and vacuum of 8 to 11.5 inches Hg.

12/21/76 Sample No. 11 was not taken: the south filter was shut down to clean the drum. The counters on the sludge pumps were switched because the numbers could not be read.

Faulty filtrate meter readings were reported to be caused by air in the filtrate from washing the drum with soap, or from CO_2 gas caused by mixing low pH clarifier underflow with waste lime. Underflow was taken in for about 2.5 hours during the first shift. Underflow was taken in for about 2.5 hours during the third shift.

The south filter operated, except as noted above, at submergence between full and 6 inches from the top, and vacuum of 7 to 12 inches Hg.

12/22/76 Full sampling at all stations. The sludge pumps were switched to repack the west side of the west pump, and the filters were switched without shutdown of the plant.

Faulty flow meter readings were reported to be caused by excessive foaming due to low-pH clarifier underflow and the factory manager was asked to raise the pH to above 8.0. Underflow was taken in for about 4 hours during the first shift, through most of the second shift, and for about 4 hours during the third shift.

The south filter operated through period No. 3 at full submergence and vacuum of 5.5 to 10 inches Hg. The north filter operated, for the balance of the day, at submergence full to 10 inches from the top, and vacuum of 4 to 10.5 inches Hg.

12/23/76 Full sampling at all stations. Replaced water and sludge packing and repaired an oil leak on the east sludge pump. Switched to the south filter to wash the north filter. Connected a 1/2-inch pipe to the filtrate line. Reset the east pump counter and placed covers over the counters (humidity had caused condensation on counter windows). Installed an air relief valve on the sludge line. Moved the polymer pump to the catwalk and placed injection point at the elbow. Tightened the sludge sampling valve.

The filtrate flow meter was still giving fault or very high and unreliable flow readings. Underflow was taken in for about 3 hours during the first shift, 5.5 hours during the second shift, and 5 hours during the third shift.

The south filter operated all day, at submergence full to half-full, and vacuum of 3 to 11.5 inches Hg.

12/24/76 No samples were collected during the third shift, but no reason was given. The bolts on the north drum agitator were tightened. The sludge pump counter was cleaned and reset. The drums were switched for cleaning. It was reported that sand in the clarifier caused the pipe to plug between 10:00 a.m. and 12:30 p.m. and again around 6:00 p.m.

Underflow was taken in for about 7 hours during first shift, through most of the second shift, and for about 5 hours of third shift.

The filtrate flow meter was still not working: air leaks were found on the vacuum tanks.

The south filter operated, except as noted above, at submergence between full and one-third full, and vacuum of 7 to 11 inches Hg.

12/26/76 Sample No. 9 was not taken: the filter was shut down to wash the drum cover. The vacuum gauge on the north filter dropped to 0 at 3:45 a.m. and the operator was unable to get any response.

The filtrate flow meter did not produce any reliable data.

Underflow was taken in for about 6 hours during the first shift, 4 hours during the second and 4 hours during the third shift.

The north filter operated, except as noted above, at submergence full to three-fourths full, and vacuum of 3 to 11.5 inches Hg except when not measured as noted above.

12/27/76 Sample No. 9 was not taken: the Mud House was shut down to wash the filter canvas. The west sludge pump was started because of a bad leak on the east sludge pump packing. Eight oz of polyelectrolyte per 50 gal were added for 2 hours. An attempt was made to man both filters: the experiment was halted after two hours because the operator reported being unable to keep up.

No filtrate flow data were entered. Underflow was taken in for about 3 hours during the first shift, 3 hours during the second shift, and 1 hour during the third shift.

The north filter operated, except as noted above, from 11:00 a.m., at submergence between full and one-third full, and vacuum of 5 to 12 inches Hg. The south filter operated also, during periods 1 (by itself) and 4 (concurrently), at full submergence and vacuum of 2 to 7 inches Hg.

12/28/76 Sample No. 11 was not taken: a bad packing on the north filter prevented switching the filters and the Mud House was shut down to wash the south filter; started the day with the north filter and switched to the south filter to wash the former at 5:00 p.m.; the need for more frequent filter washings was blamed on a possible overdose of polymers during tests from the previous day. Sand found in the clarifier was traced back to a bypass valve inadvertently left open on the classifier at the Beet Handling House. The waste lime was reported cold and wet.

No filtrate flow data were recorded.

Underflow was taken in for about 4 hours during first shift, 1 hour during the second shift, and 2 hours during the third shift.

The north filter operated, as noted above, at submergence between 4 and 12 inches from the top, and vacuum of 11 to 15 inches Hg. The south filter operated, as noted above, at submergence between full and 6 inches from the top, and vacuum of 4 to 12 inches Hg.

12/29/76 Sample No. 12 was not taken but no reason was given. Replaced the packing on the north drum vacuum line and switched to it during periods 7 and 8; worked on the polyelectrolyte pump and added 12 oz polyelectrolyte per 50 gal for 2 hours; switched the sludge pumps at 1:00 a.m. when the west pump lost its packing.

The filtrate flow meter was installed on the intake line to the pumps and started to produce flow data; the flow rate was calculated at 49.3 gpm for 13 hours of operation. Underflow was taken in for about 4 hours during the first shift, 4 hours during the second shift, and 2 hours during the third shift.

The north filter operated, as noted above, at submergence between full and three-fourths full, and vacuum of 3 to 11 inches Hg. The south filter operated throughout the day, except as noted above, at submergence between full and 12 inches from the top, and vacuum of 5 to 10 inches Hg.

12/30/76 The first three samples were not taken; the Mud House was shut down at the beginning of the day until 3:00 p.m. by repair work on high-voltage lines by the power company. The north drum was down to repair broken packing gland on the vacuum line: an air leak was found on the vacuum pump packing. Repacked the west side of the west sludge pump. (Sample 8 was not taken, but no reason was given.)

The filtrate flow meter data yielded a calculated flow rate of 30.6 gpm for 16 hours of operation. Underflow was taken in for about 3 hours during the first shift, 6 hours during the second shift, and 4 hours during the third shift.

The south filter operated, except as noted above, at submergence between full and 12 inches from the top, and vacuum of 5 to 10.5 inches Hg.

12/31/76 Full sampling at all stations.

A filtrate flow rate of 27.3 gpm for 22 hours of operation was calculated. Underflow was taken in during most of the first shift, for about 6 hours during the second shift, and very little or none during the third shift.

The south filter operated at submergence between full and half-full and vacuum of 4 to 11 inches Hg.

Comment: An unusual day with no filter washes reported. This, coupled with a steady filtrate flow rate and a high filtrate temperature of 29°C to 34°C, led to the conclusion that minimal amounts of underflow were processed.

1/2/77 Full sampling at all stations. Began filtering with the south filter then switched to the north filter at 10:00 a.m., and back to the south filter at 7:00 p.m. (suspect filter washing as reason for switching).

A filtrate flow rate of 36 gpm for a 24-hour period was calculated. Underflow was taken in for about 2 hours during the first shift, 1 hour during the second shift, and 1 hour during the third shift.

The north filter operated, as noted above, at submergence between full and 6 inches from the top, and vacuum of 6 to 8 inches Hg. The south filter operated, as noted above, at submergence between full and 3 inches from the top, and vacuum of 5 to 7 inches Hg.

1/3/77 Underflow samples No. 2 and 3 were not taken: the clarifier was shut down between 10:30 a.m. and 1:45 p.m.; the pump's variable speed control was jammed. The clarifier shutdown caused the submergence level in the north filter to drop to a low level. Power was lost for about 2 minutes, at 11:05 a.m., due to a blown transformer at the power station. Switched to the north filter at 8:40 a.m., switched to the south filter at 8:00 p.m. and back again to the north filter at 6:00 a.m. (suspect filter washing as reasons for switching).

A filtrate flow rate of 19.6 gpm for 8 hours of operation was calculated. Underflow was taken in for about 7 hours during the first shift, 6 hours during the second shift, and 3 hours during the third shift.

The north filter operated, as noted above, at submergence between full and 8 inches from the top, and vacuum of 3 to 14 inches. The south filter operated, as noted above, at full submergence, and vacuum of 5 to 14 inches Hg.

1/4/77 The first four samples were not taken: the Mud House was shut down from 9:00 a.m. to 4:30 p.m. for flow measurement trials by S&P. A broken stud on the sludge pump was replaced and an oil leak was repaired. (The second shift started filtering with the north filter, then switched to the south filter at 7:00 p.m. and back to the north filter at 1:00 a.m., apparently to wash the filters.)

A filtrate flow rate of 27 gpm for 8 hours of operation was calculated. Underflow was taken in for about 4 hours during the second shift and about 4 hours during the third shift.

The north filter operated, as noted above, at full submergence, and vacuum of 5 to 12 inches Hg. The south filter operated, as noted above, at submergence between full and three-fourths full, and vacuum of 9 to 15 inches Hg.

1/5/77 The first four samples were not taken: the Mud House was shut down to allow for calibration of underflow pump and bypass valve. The second shift began filtering with the north filter, then switched to the south filter at 7:00 p.m. and back to the north filter at 3:00 a.m. (apparently to wash the filters).

A filtrate flow rate of 36.7 gpm for 10 hours of operation was calculated. The manufacturer returned the underflow flow meter to the site. An attempt was made to install it on the section of pipe leading to the mixing tank, but aeration, when opening the bypass valve, caused the meter to malfunction. The meter was then reinstalled at its previous location, but after several hours of observation, it was concluded that solids in the underflow made this liquid unmeasurable by this method. The data on the estimates of underflow taken in were inconclusive.

The north filter operated, as noted above, at submergence between full and 8 inches from the top, and vacuum of 7 to 14 inches Hg. The south filter operated, as noted above, at submergence between full and 24 inches from the top, and vacuum of 5 to 8 inches Hg.

1/6/77 Samples No. 2 and 3 were not taken: the Mud House was shut down because no waste lime was available from the factory. Sample No. 5 was not taken: both filters were washed and switched to the south filter; then back to the north filter to clean the south filter at 10:00 p.m. (no shutdown). The east sludge pump blew a seal, causing mud to spray onto the floor; replaced the oil ring and a valve stem.

A filtrate flow rate of 22 gpm for 6 hours of operation was calculated. Underflow was taken in for about 2 hours during the first shift and for about 2 hours during the second shift. The third shift did not record any information.

The north filter operated, as noted above, at submergence between full and half-full, and vacuum of 5 to 15 inches Hg. The south filter operated, as noted above, at submergence between full and 8 inches from the top, and vacuum of 9 to 11 inches Hg.

Note to the Reader: Two types of accounts are presented in the remainder of this log summary. The accounts for 1/8/77 and 1/9/77 conform to the format followed up to this point and are based on data recorded by the Mud House operators. The other more detailed information is described in the order of occurrence and as recorded by an observer monitoring the activities of the first shift exclusively.

1/7/77

8:00 a.m. The south filter was operating but the blower was failing: the cake was not being properly blown from the filter cloth.

A sludge pump seal was out and sludge was being squirted onto the floor. According to the foreman, it had been out from one to two hours.

8:05 a.m. The south filter was shut down for sludge pump repairs. All clarifier underflow and waste lime were being bypassed to their respective ponds.

8:20 a.m. The sludge pumps were switched and the crew was preparing to start filtering again with the north filter.

8:21 a.m. The welder started installation of a cyclone in the clarifier underflow piping system. As the welding machine was plugged into the wall receptacle, a circuit breaker blew up and all electrical power was lost.

8:50 a.m. The fuse was replaced and electrical power was restored. It appeared that the receptacle collected water from washing down equipment and moisture within the building.

During the plant shutdown caused by the power outage, all materials were bypassed to the outside. During this down time, the filter cake froze partially in the discharge line, causing a backup and overflow in the hoppers. During this time, and with the sludge pumps discharging at full stroke, an oil line in the hydraulic system broke and had to be repaired.

10:00 a.m. The north filter was put in operation.

10:18 a.m. The east valve was set at 1-1/4", 25 gpm, clarifier pump set at 30 percent. Almost immediately the valve was reopened to bypass the underflow because of an apparent high volume of waste lime coming from the factory. The waste lime was flowing at about 108 gpm and the flow rate appeared to vary considerably.

11:15 a.m. The east valve was set at 1-1/4", 25 gpm, clarifier pump set at 30 percent.

11:56 a.m. Collected samples.

12:15 p.m. With a filter drum submergence of one-half to three-quarters full, the mixing tank's rear chamber began to overflow while the liquid level at the main chamber was about one foot from the top. The east valve was opened to bypass underflow.

Comment: The waste lime and underflow enter the rear chamber of the tank and the interchamber flow is through the bottom of the partition. The settling of the denser materials, which must pass first, causes the uneven levels between the two chambers with resulting overflowing of the rear chamber.

The waste lime flow rate was calculated at 108 gpm, and the underflow at 25 gpm, clarifier pump set at 30 percent.

1:00 p.m. Collected samples.

2:00 p.m. Collected samples.

3:00 p.m. Operations were switched from the north filter to the south filter. The east underflow valve was set at 1", 55 gpm, clarifier pump set at 30 percent. The waste lime flow rate was calculated at 81 gpm. The filter tanks had to be kept half-full or less because of a bearing leak in the shaft.

Under the above conditions, the following was observed: 1) The cake looked good; 2) It was necessary, for a short time, to bypass some of the mix until the liquid levels in the tanks were stabilized. This was probably caused by the leaky bearing and the variation of waste lime flow. The levels were stabilized, and no further adjustments were required; 3) The filtrate flow rate varied from 20 gpm, when only waste lime was processed, to 72 gpm when 55 gpm of underflow was added; 4) The effective stroke on the sludge pump decreased from minus 2" to minus 3".

3:25 p.m. Collected samples.

3:53 p.m. Collected samples.

3:55 p.m. The east valve was set at 3/4", 95 gpm, clarifier pump set at 30 percent.

Under these new conditions, the following was observed: 1) The cake still looked good; 2) Same as before; 3) The filtrate flow increased to about 100 gpm, but the flow meter started to fault due to air bubbles created by the higher flow. As aeration continued to occur, the flow meter went into a steady fault condition that lasted until the end of the shift; 4) The effective sludge pump stroke increased from minus 3" to minus 2".

A filtrate flow rate of 23.3 gpm for 4 hours of operation was calculated during the first shift; during the second and third shifts it was 35.3 gpm for 12 hours of operation.

1/8/77 Samples No. 5 and 6 were not taken: the Mud House was shut down to wash the filters. Began operations with the north filter; switched to the south filter after the shutdown; switched back to the north filter, without shutdown, at about 4 a.m.

A filtrate flow rate of 15.8 gpm for 16 hours of operation (shutdown period excluded) was calculated. No data on underflow distribution was recorded.

The north filter operated, as noted above, at full submergence, and vacuum of 5 to 16 inches Hg. The south filter operated, as noted above, at submergence between full and 4 inches from the top, and vacuum of 8 to 9 inches Hg.

1/9/77 Samples No. 6, 7, and 8 were not taken: the Mud House was shut down to wash the filters, repair a leaking water line on the east sludge pump, repack a shaft on the west sludge pump, and to clean the filter of one of the blowers. Began operations with the north filter; switched to the south filter, without shutdown, at 1:00 p.m. and continued after the shutdown; switched back to the north filter, without shutdown at 5:00 a.m. Broken air lines inside the north filter were reported causing problems with the lifting of the cake from the drum.

A filtrate flow rate of 25.9 gpm for 14 hours of operation (shutdown period excluded) was calculated. Underflow was taken in for about 1 hour during the first shift and for about 1 hour during the second shift; the third shift did not record any data.

The north filter operated, as noted above, at submergence between full and half-full, and vacuum of 5 to 9 inches Hg. The south filter operated, as noted above, at submergence between full and three-fourths full, and vacuum of 7 to 9 inches Hg.

1/10/77

8:00 a.m. The north filter was operating, but the blower was working only on half of the drum. The two previous shifts had trouble with the blowers on both filters.

The previous shift was filtering waste lime only. The filtrate was reading 20 gpm and the effective stroke on the sludge pump was minus 2". These conditions appeared to be normal when processing straight waste lime.

The flow meter on the underflow line was no longer working.

Both drums were having bearing leaks. The foreman did not want to start introducing underflow until repairs on the blowers had been made. Everyone was busy with repairs and the Mud House could not afford any additional problems at this time. There was concern about freezing of the discharge line.

9:00 a.m. The east valve was set at 1-3/4", (zero underflow), clarifier pump set at 34 percent.

9:15 a.m. Collected samples. The clarifier operator did not show up, and there was a buildup of about 4 feet of mud. The clarifier pump was set at 34 percent to discharge more mud out of the clarifier. The total flow out of the clarifier was estimated at 180 gpm.

10:30 a.m. The crew was still working on the south filter. The north filter was still processing straight waste lime.

Problems had been experienced in keeping the desired liquid levels in the mixing tank and in the filters. The level indicator must be flushed down periodically to avoid false level readings due to clogging.

11:10 a.m. Started operating the south filter. The waste lime flow rate could not be determined because the flow of waste lime to the filter tank could not be cut off and all of it was needed to keep the filter tank full.

11:14 a.m. The east valve was set at 1-3/4", 50 gpm, clarifier pump set at 34 percent.

11:24 a.m. Collected samples. The filter cake was rather thin and wet, the filter flow rate had increased to 60 gpm, and the effective stroke on the sludge pump was reduced from minus 16" to minus 28".

11:40 a.m. The east valve was set at 1-1/2", 80 gpm, clarifier pump set at 34 percent.

12:24 p.m. Collected samples. The filtrate flow rate had decreased from 60 gpm to 20 gpm, the cake was still coming out thin but dry, and the effective stroke of the sludge pump had increased from minus 28" to minus 24".

1:00 p.m. Collected samples. The same conditions as the 12:24 time prevailed.

1:35 p.m. The mixing tank and filter drum reached their maximum level. Some of the mix from the mixing tank was bypassed to hold a steady level. The bearing was still leaking even though the filter drum had been running close to full.

2:00 p.m. Collected samples. Conditions remained unchanged. The sludge pump developed a pressure seal leak. (See 1/7/77 notes for this same problem.) The bearing was still leaking.

2:10 p.m. The filter cake in the discharge line had frozen. The sludge was being discharged into the pond through a valved tee near the building. The crew was working to correct the problem. It had become necessary to bypass the mix again. About 1,950 gals were bypassed each time.

2:20 p.m. The east valve was set at 1", 130 gpm, clarifier pump set at 34 percent. The quality of the filter cake seemed to improve: it was still thin but drier and cutting better. (See final note of the day for reason.)

2:38 p.m. The east valve was set at 3/4", 155 gpm, clarifier pump set at 34 percent.

2:45 p.m. The filter cake discharge line broke at the tee connection outside the building, making it necessary to stop filtering and to bypass waste lime and underflow until repairs were made.

3:30 p.m. The tee connection was repaired, but due to the prolonged down time, the sludge had frozen in the line.

4:30 p.m. At the end of the shift, the sludge discharge line was still frozen and the filters were still shut down. The filtrate flow rate was calculated at 23.5 gpm for 5 hours of operation.

Comment: It was discovered that the clarifier pump had changed percent load settings throughout the day. The operator usually adjusts the setting, but since there was no one in attendance, today's estimated clarifier flow rates are not reliable. It was set at 34 percent around noon, and at 28 percent by 2:30, thus indicating that very little or no clarifier underflow was taken in during that period.

1/11/77

8:00 a.m. The south filter was operating at the start of the shift. The east valve was wide open and only waste lime was being filtered.

8:20 a.m. Collected samples. The filtrate flow was 30 gpm; clarifier pump set at 34 percent; the effective stroke on one sludge pump was minus 16".

11:15 a.m. Collected samples at 9:00, 10:00, and 11:00; conditions remained similar to those reported at 8:20. All settings were still the same. No underflow was being processed.

The flow of clarifier underflow into the mixing tank was measured and compared to the setting on the east valve to verify correctness of the flow chart: the chart was found to be correct.

11:30 a.m. A decision was made by MINN-DAK not to process any underflow on this date. Indications were that the clarifier underflow lowered the temperature of the mix to a point where the cake readily froze in the discharge line outside. This was suspected for the line freezing yesterday. MINN-DAK suggested that underflow be processed for a short period every 2 hours to avoid freezing the discharge line.

12:00 p.m. Started operating the north filter. Both filters were working but were having problems with the blowers. The cake was being blown in the proper manner in only about one half of the drum.

12:25 p.m. Collected samples.

1:00 p.m. The temperature of the waste lime as it discharged in the mixing tank was 40°C. The temperature of the cake out of the filter was 34°C. The outside temperature was -24°C.

1:50 p.m. Collected samples.

3:00 p.m. The cake had looked good up to this time, but the quality was beginning to deteriorate.

3:15 p.m. Collected samples.

4:00 p.m. Collected samples. The filtrate flow was calculated at 47.3 gpm for 22 hours of operation.

Comment: The settled solids profile in the clarifier appears to have peaks and valleys and the operator usually sets the snout for the peaks only. This means that, as the snout sweeps the clarifier, the mud sucked into the pump intake exhibits a variable density: heavy through the peaks and light through the depressions as more water is taken in.

1/12/77

8:00 a.m. The north filter was operating at the start of the shift. It had been running for 8 hours with only waste lime being processed during this time. The quality of the cake appeared poor and the filtrate meter read 20 gpm, about the normal flow for straight waste lime filtration.

The clarifier operator did not show up again on this date. The previous shift reported that the underflow pipe had been plugging up often and attributed this to very dense mud being sucked by a low setting of the snout.

12:15 p.m. Collected samples.

12:30 p.m. Switched operaton to the south filter. The east valve was set at 1-3/4", 25 gpm, clarifier pump set at 32 percent; the waste lime was calculated at 65 gpm; the outside temperature was -27°C; wind 5-10 mph.

2:00 p.m. The mixing tank solution level was holding well; the cake was a medium brown, .05' thick, and cutting well.

2:15 p.m. Collected samples.

2:23 p.m. The east valve was set at 1-1/2", 60 gpm, clarifier pump set at 32 percent; the waste lime flow was calculated at 56 gpm; the tank solution was holding well; the cake was dark brown, .05' thick, not cutting as well as at 2:00, but still acceptable.

4:30 p.m. Were still processing the same ratio on the mix at the end of the day. The quality of the cake had decreased to a point where the filters would have to be switched soon.

The filtrate flow rate was calculated at 34 gpm for 7 hours of operation.

1/13/77

8:00 a.m. Collected samples. The north filter was operating but no clarifier underflow was being processed. The filter had been running since about 5:00 a.m., and only the east one-third of the filter had been producing a good cake. It was determined that the pipe feeding the west end of the tank had plugged.

The cake began to deteriorate at the center of the filter. (Under normal conditions, the denser material separates from the water near the point where the mix is introduced at both ends of the tank; therefore, there are less solids at the center of the filter than at either end; in addition, a thin slurry containing sand is pumped up and is applied at the top center of the drum.)

It was observed that when clarifier underflow was introduced in the mix, the filter would produce a good cake for a limited time only.

9:00 a.m. Collected samples.

9:30 a.m. The cyclone was put in operation for a short time.

10:00 a.m. Collected samples.

11:20 a.m. Collected samples. The east valve was set at 1-1/4", 100 gpm, clarifier pump set at 32 percent; waste lime flow was calculated at 71 gpm.

12:10 p.m. Collected samples. The filtrate flow meter read 60 gpm; the cake had a dark gray color, high moisture content, but appeared solid and cutting well; the volume in the mixing tank was slowly increasing.

12:25 p.m. The cake was steadily getting thinner and wetter; the east valve was set at 1-1/2", 60 gpm, clarifier pump set at 32 percent.

1:00 p.m. Collected samples. The waste lime flow was calculated at 90 gpm, and the total flow to the mixing tank was estimated at 150 gpm.

2:00 p.m. Collected samples.

2:30 p.m. The bolts holding the face plate on the end of the drive shaft to the filter frame were sheared off. This marked the end of monitoring of the Mud House because MINN-DAK decided to bypass the total underflow for the balance of the campaign. Waste lime would continue to be filtered until the end.

4:00 p.m. The filtrate flow rate was calculated at 20.6 gpm for 8 hours of operation.

END

APPENDIX C

MONITORING AND ANALYTICAL PROGRAMS

SAMPLE COLLECTION AND ANALYSIS, AND QUALITY CONTROL

Campaign Period Sampling Procedures

Sample aliquots were collected every odd-numbered hour and composited into daily samples Monday through Saturday each week of the study. Each Mud House shift operator was responsible for entering data in the Mud House log and seeing that sample aliquots were collected. Each morning MINN-DAK personnel took the filtrate (F), clarifier underflow (CU), filter cake (FC), and cake storage area (CSA) samples to the MINN-DAK laboratory. The waste lime (WL) sample aliquots were collected in the plant and composited in the laboratory by MINN-DAK laboratory personnel.

Specific instructions for the collection of each type of sample were provided to the operators. Demonstrations of sampling technique were also performed.

None of the samples were preserved before analysis. In general, analyses were started nine to ten hours after the last sample aliquot was added to the composite sample.

Procedures--

The analytical procedures used were:

1. COD, Total and Soluble--The procedure followed is published in section 508, pp. 550-554, "Standard Methods for the Examination of Water and Wastewater," 14th ed., APHA, AWWA, WPCF (1975) (abbreviated SMEWW). The quantities of reagents used were those given in Table 508:I on page 553 of the above reference, for a 20.0 ml sample size. For COD values greater than 1000 mg/l, a suitable portion of sample was diluted to a known volume with distilled water.

The soluble COD was determined by the above procedure on the filtrate obtained by filtration of a sample aliquot through a 0.45 micron (pore diameter) membrane filter This definition of the soluble or dissolved fraction of a constituent is found on page v of "Methods for Chemical Analysis of Water and Wastes," USEPA (1974), document number EPA-625-/6-74-003.

2. Calcium, Total and Soluble--Calcium was measured by titration with EDTA according to the procedure of section 306C of SMEWW.

3. pH Values--The pH values of the samples were measured with an electronic pH meter which employed a glass electrode and was equipped with temperature compensating circuitry. Commercially available buffers were used to calibrate the instrument. The procedure is published on pages 460-465 of SMEWW.

4. Temperature--Sample and ambient temperatures were measured with a stainless steel dial thermometer with 1°C divisions.

5. Total Solids (TS) and Total Volatile Solids (TVS)--Total solids were determined by a gravimetric procedure similar to that in section 208A of SMEWW. A 3-5 g sample was dried overnight in a mechanical convection oven operated at 105-110°C.

To determine TVS, the TS sample, after cooling and weighing, was ignited at 550°C for one hour. No decrepitation of sample was observed.

6. Bulk Density--Bulk density was determined by weighing a measured volume of sample. The samples were measured by filling a porcelain crucible; the volume of the crucible was determined by filling with water and weighing.

Quality Control--

1. COD--A standard KHP solution was analyzed daily. One sample per day was analyzed in duplicate so that, in the course of a week, one sample from each sample stream was analyzed in duplicate.

2. Calcium--The same program of duplicate analyses used for COD was also followed for the calcium determinations.

3. pH--The pH meter used was standardized daily with commercial buffers.

4. Total Solids (TS) and Total Volatile Solids (TVS)--The same program of duplicate analyses followed for COD was also followed for the TS and TVS analyses.

5. Bulk Density--Bulk density was determined in triplicate daily for each of the four samples (CU, FC, CSA, WL).

6. EPA Reference Samples--A duplicate set of EPA reference samples was analyzed for total COD, pH, and total dissolved solids by Sverdrup & Parcel (S&P). The analyses were performed by an S&P chemist at its St. Louis, Missouri laboratory, and by a technician at the MINN-DAK laboratory in Wahpeton, North Dakota. The results obtained are presented in Table C-1 below.

TABLE C-1. QUALITY CONTROL RESULTS

Parameter	Sample Number	EPA Corvallis, OR	Value Reported By S&P Chemist St. Louis, MO	 S&P Technician Wahpeton, ND
Total COD, mg/l	1	770	774	750
Total COD, mg/l	2	2,310	2,210	g.t. 1,900*
pH, units	1	7.7	7.85	8.30
pH, units	2	8.6	7.98	8.25
TDS, mg/l	1	717**	680#	935#
TDS, mg/l	2	3,180**	3,640#	3,640#

* g.t. signifies greater than

** Dried at 180°C

# Dried at 103-105°C

APPENDIX D

MUD HOUSE OPERATING LOG
SAMPLING INSTRUCTIONS

1. General

Each shift operator will be responsible for making entries in the appropriate spaces provided, and at the required two-hour intervals. The odd-hour intervals are guides only but should be adhered to as closely as possible. Any deviations should be noted in the "Comments" block.

2. Date

The first shift operator will enter the date. The second and third shift operators will insure that this entry is made and that it is entered correctly.

3. Time of Entry

All time recordings will be made from the same Mud House clock or from timepieces synchronized with it.

4. Mud House Ambient Temperature

Record ambient temperature by reading the thermometer provided at the filtrate return sampling station. Record temperature to the nearest 1°C. Record time to the nearest 5 minutes.

5. Liquid Sample Collection

This applies to the Thickener Underflow and the Filtrate Return sampling stations. Each station will have the following equipment: flow meter, thermometer, waste bucket, collecting bucket, measuring bottle, funnel, stirrer and sample container. Collect the sample according to the following procedure:

5.1 Open sampling valve and waste about 1/2 gallon in waste bucket.

5.2 Collect about 3/4 gallon sample in the sampling bucket; close valve.

5.3 Dip in and fill 1/2 pint measuring bottle immediately. If this is not done immediately, and/or if solids begin to settle, stir the contents of the sampling bucket prior to filling the measuring bottle.

5.4 Immerse the thermometer in the sampling bucket.

5.5 Pour half of the sample in the sampling bottle into the sample container with the aid of the funnel. Swirl the remaining half to insure complete mix and pour in the sample container. Except during sample collection times, the sample container should remain capped.

5.6 Read the thermometer and record the temperature of the sample in the log to the nearest degree. Wipe the thermometer.

5.7 Read the flow meter and record flow rate, total gallons and time, to nearest 5 gpm, 100 gallons, and one minute, respectively.

5.8 Proceed to the next task. Do not pause to clean equipment until all other data collecting and recording tasks have been completed.

6. Lagoon Valve

Record the times at which the valve diverting thickener underflow to the lagoon is opened and closed, to the nearest minute. Record the aperture of the valve; record number of turns; or if valve is a rising stem type, measure and record the height of the valve stem.

7. Filter Operation Data

The filters are identified as north and south filters. Record in the log the seconds it takes the drum to complete one revolution, the inches out of the liquid level, the vacuum applied in inches of mercury, and the time at the completion of the readings. Proceed to obtain the cake sample.

8. Filter Cake Sampling

Stations will be marked to indicate four points at which samples will be obtained. Sampling equipment will include a long-handled spoon to reach the cake as it is dislodged from the filter, and a wide-mouth plastic jar to collect the cake samples. Collect cake samples by filling spoon and deposit contents into the jar. This procedure will be demonstrated during the first week of sampling. The container will be kept tightly closed between collections to prevent the drying of the cake.

9. Cake Storage Sampling

Obtain cake storage sampling from the self cleaning sampling valve located downstream from the sludge pumps. A sampling ladle and a wide-mouth plastic jar sample container are provided. Collect sample by filling the ladle and deposit contents into the jar. Keep jar tightly closed between sample collections.

10. Sludge Pumps

Stroke counters will be installed on the sludge pumps. Record the times at which the pumps are turned on and off and record the pump count and setting and/or the volumetric displacement of the setting; record only the initial (9 a.m.) and final (7 a.m.) counts and settings.

11. Polyelectrolyte

MINN-DAK, on its own initiative, is presently experimenting with polyelectrolytes. Record the times polyelectrolyte is added to the mixing tank (on and off), the feed rate (gal/hour or convenient units), the concentration (weight/volume or convenient units) and the type of polyelectrolyte. Note any changes on any of the above and record.

12. Cleaning of Sampling Equipment

After all sampling collection and data recording have been properly carried out, proceed to clean sampling equipment in preparation for the next collection. Dump excess sample and rinse sampling bucket, measuring bottle, and funnel. Clean cake sampling device.

13. Comments

Enter here any unusual activities not reflected under itemized instructions. Special attention should be given to breakdown of equipment. Record any changes in operation and reasons for them.

14. Waste Lime Sampling

Waste lime samples will be collected at the factory by laboratory personnel on the same schedule as the Mud House. Samples are routinely collected by a laboratory technician, who will collect enough samples to make the composite for the analysis of this stream.

GLOSSARY

anaerobic: Living or active in the absence of free oxygen.

beet pulp: The vegetable matter left after sugar is extracted from cossettes.

beet wheel: A large wheel with baffles projecting radially inward from the surface of the perforated rim, and used to raise beets to a higher plane and separate them from the flume water; e.g., as from a flume to a beet washer.

biochemical oxygen demand (BOD_5): A measure of the oxygen demand in sewage and industrial wastes or in a stream, determined by bioassay techniques.

campaign: The period of the year during which the beet plant makes sugar.

clarification: The process of removing undissolved (suspended) materials from a liquid. Specifically, the removal of solids by settling.

COD: Chemical oxygen demand. A measure of the oxygen demand equivalent of that portion of matter in a sample that is susceptible to oxidation by a strong chemical oxidant.

filtrate: Liquid after passing through a filter.

filtration: Removal of solid particles from liquid or particles from an air or gas stream by a permeable membrane or layer of granular material.

flume wastewater: The term normally applied to the discharge of flume water that is employed to convey beets into the beet sugar processing plant.

lime cake: The residue resulting from clarification and purification of the raw sugar juice by heating, lime addition, and precipitation in a two-step process through carbon dioxide addition. The cake contains both organic and inorganic impurities.

lime mud slurry: The product resulting from the addition of water to lime cake to facilitate pumping of the material for disposal.

lime pond: A large diked area in which lime mud slurry or waste filter cakes are held.

pH: A measure of the relative acidity or alkalinity of water. A pH value of 7.0 indicates a neutral condition; less than 7 indicates a predominance of acids; and greater than 7, a predominance of alkalis. There is a 10-fold increase (or decrease) from one pH unit level to the next, e.g., 10-fold increase in alkalinity from pH 8 to pH 9.

sedimentation: The falling or settling of solid particles in a liquid, as a sediment (clarification).

slicing capacity: Processing capacity. The number of tons of sugar beets a plant is capable of processing in a 24-hour period of time.

sludge: The settled mud from a thickener or clarifier. Generally, any flocculated, settled mass.

Steffen process: A process employed at some beet sugar plants for recovery of additional sucrose from molasses. The process is carried on in conjunction wth the main sugar extraction process at non-Steffen or "straight-house" plants. The process consists of the addition of finely ground calcium oxide to dilute molasses under low temperature conditions. Sugar, Steffen filtrate, and insoluble calcium saccharate are produced, filtered out, and generally reused at the main purification step of the normal "straight-house" extraction process.

supernatant: The liquid layer floating above the surface of a layer of solids or sludge.

total suspended solids (TSS): Solids found in wastewater or in the stream which in most cases can be removed by filtration. The origin of suspended matter may be man-made wastes or natural sources such as silt from erosion.

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